MU17008: Understanding and managing the impacts of climate change on Australian mushroom production

Desktop review

APPLIED HORTICULTURAL RESEARCH ABN 58 134 308 982
Suite 340, Biomedical Building, 1 Central Avenue, Australian Technology Park, Eveleigh NSW 2015
info@ahr.com.au | +612 8627 1040 | www.ahr.com.au

Author: Gordon Rogers

Mobile: +61 418 51 7777

Email: gordon@ahr.com.au

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Executive summary

Uniquely among horticultural industries, mushrooms are produced in precisely managed, environmentally controlled conditions. Despite this, the industry is still vulnerable to climate related risks. Changes in temperature and rainfall, together with global efforts to reduce emissions, will inevitably affect input costs, availability and social licence to operate.

Production of greenhouse gasses including CO_2, methane and nitrous oxide has been rising since the beginning of the industrial age. Average temperature rises in the order of 1-2^{o}C are accompanied by significant increases in extreme weather events such as heatwaves, drought, sleet and storms. As sea and surface temperatures rise, rainfall patterns will change, and events such as the 2019-2020 Australian summer of drought, heat and bushfires will increase in frequency.

Greenhouse gas emissions: Three life cycle assessment studies (Australia, the USA and Spain) were reviewed which analysed greenhouse gas emissions from mushroom farms. These calculated emissions of 2.1 to 4.4 kg CO_2-e per kg mushrooms produced. Most of the emissions come from energy used for heating and cooling, from compost production, and – particularly in Australia – from transporting peat. However, it should be noted that none of these studies included emissions as a result of peat mining, which are considerable. This issue aside, the studies suggest that greenhouse gas emissions from mushroom production are less than those for lettuces and strawberries, but higher than snow peas or chillies.

Predicted changes to the climate in each of the mushroom and compost producing regions: The predicted climate changes by 2070 were modelled for the following six regions in Australia:

- Sydney and the Hunter Valley, NSW
- Brisbane, Queensland
- Perth, Western Australia
- Mildura and Melbourne, Victoria
- Hobart, Tasmania
- Adelaide, South Australia

Potential changes in annual climate are provided for 30 (2050) and 50 years from now and include maximum and minimum temperatures, rainfall, relative humidity, solar radiation and windspeed. These are not predictions of what the climate will be like, but provide an indication of potential future climates depending on how Australia and the rest of the world respond to the challenge of reducing greenhouse emissions. Currently, global emissions are tracking on the most extreme scenario (RCP8.5). The potential climate extremes are provided for the hottest day and coldest night to give an indication of what potential changes in extremes could occur in 30 and 50 years under the two scenarios.

Alarmingly, the average number of days above 35^{o}C over the past 12 months (May 2019 – April 2020) for most regions in Australia were already close to, or exceeding, the long term average number of hot days (over 35^{o}C) expected by 2050.

Expected impact on pests and diseases: The following pest and disease-related issues are expected to increase in severity or significance with climate change:

- Dispersal of established diseases because greater sciarid and phorid fly activity and increased populations will spread disease
- Dry conditions will facilitate air and dust-borne pathogen dispersal
- Increased incidence of mites and nematodes

- Increase in weed molds
- Establishment of emerging diseases will increase facilitated by increased insect activity. The greatest risk is from Trichoderma aggressivum f. aggressivum as it is adapted to bulk Phase III handling systems

There is expected to be no increase in the introduction of new diseases into Australia or the local expression of established diseases because the conditions are controlled within the growing rooms. For more information refer to the section on pests and disease impacts.

Risk and opportunity: The project team consulted with 20 mushroom producers, representing 73% of Australian production, and seven composters. We collected their views on climate risk and preparations they have already made, as well as those they are considering, to manage climate-related impacts on their businesses, energy usage and costs. Based on the review and industry consultations, the team identified the following major risks and opportunities facing the Australian mushroom and compost production industries:

1. Availability of peat for casing
2. Availability, cost and quality of wheat straw for compost
3. Availability and quality of manure for compost
4. Impacts of temperature extremes on compost production, growing and transport
5. Energy – reliability of the power grid and costs of electricity and gas; on farm power generation
6. Government emissions control policies
7. Water availability, cost and quality for compost production and mushroom growing
8. Pests and diseases, increased fly activity spreading disease, weed molds and Trichoderma

We have produced concise factsheets for each of the risks and opportunities listed above. The factsheets will be used for industry communication, and also summarises the key findings of the project in relation to climate risk.

Adaptation and mitigation options: The team reviewed adaptation and mitigation options currently used in Australia and internationally, and developed ten case studies that outline opportunities for each option. These options will inform the risk mitigation strategy and inform the R&D plan. The review identified the following ten adaptation and mitigation opportunities, and produced a factsheet outlining current knowledge in relation to key opportunities:

1. Biogas for power generation using spent mushroom compost
2. Reuse of spent mushroom compost as compost and/or casing
3. Government funding available including carbon credits and direct action
4. Greenhouse gas emissions from the mushroom industry
5. Load shedding: use of generators to manage risk to the electricity supply and reduce peak energy charges during periods of peak demand.
6. Energy recovery units: extracting and reusing energy e.g. heat from exhaust gases
7. Local desalination of irrigation and washing water using solar
8. Solar options and better energy deals
9. Separating peat from mushroom compost and reusing components
10. Composted recycled organics as a casing layer ingredient

Recommendations: The nine recommendations from the study are to:

1. Identify and test alternative casing materials
2. Optimise compost made from lower quality, shorter straw and different manure sources
3. Evaluate the use of soil moisture sensors for managing irrigation in mushroom growing
4. Develop a smart cookout approach using qPCR disease identification to determine pathogens present and determine when cookout is needed.
5. Understand cookout timing and temperatures required to control specific diseases in growing rooms.
6. Investigate likely changes in mushroom disease, including smoky mould
7. Investigate the technical feasibility and marketing opportunities of carbon neutral mushrooms
8. Establish a solar buying group for mushroom producers
9. Pilot biogas energy generation on-farm

1 Introduction

The mushroom industry is likely to be one of the least vulnerable of all the 'horticultural' industries to climate change. Production occurs inside precisely controlled and monitored environments. Computerised systems manage temperature, humidity, CO_2 and moisture to optimise productivity and control pests and diseases at every stage. Even the compost is largely produced inside constructed chambers, sheltering it from extremes of sun, wind and rain.

Nevertheless, climate variability and change represent major challenges to the mushroom industry. While the core activity of mushroom production occurs inside growth rooms, there are a myriad of climate-related risks that are likely to threaten the technical and economic viability of Australian mushroom producers, compost producers and support industries.

Rainfall patterns are changing, droughts are intensifying, average temperatures have increased and, importantly, the frequency of extreme weather events has increased.

Managing climate change is a triple bottom-line issue, with environmental, economic and social implications. The Australian mushroom industry is not alone in preparing for it. Directors of Australia's biggest companies consider climate change a key long-term issue that needs to be addressed by business[1].

How would climate change affect the viability of the Australian mushroom industry? What are the main risks facing the industry? If the industry clearly understands these risks, will they will be in a stronger position to deal with them?

Significant climate-related risks and opportunities facing the industry include:

- Changed weather patterns: Higher temperatures, droughts and extreme weather which disrupt farm operations and strain environmental management systems
- Reductions in the supply and quality of inputs e.g. wheat straw, peat, water
- Energy cost and availability for growing rooms and compost making
- Government policies in Australia and internationally
- Consumers and marketing: Could mushrooms could be the first carbon neutral agricultural industry?

This review summarises the latest science on climate change and the expected impacts that may affect the mushroom industry. It also reviews what mushroom producers and compost producers around the world are doing and can do in the future to adapt to the impacts of climate change.

[1] ABC News 25th October 2018. https://www.abc.net.au/news/2018-10-25/why-company-directors-have-started-caring-about-climate-change/10423658

2 Australian Mushroom Industry

The Australian mushroom industry (June 2019) produced approximately 72,000 tonnes of mushrooms with just 3% sent to processing. Despite a slight increase in production compared to 2018, farm gate values fell by 4% from $457m to $438m.

The supply per capita was 2.9 kg, based on the volume supplied, which has remained fairly steady for the last three years. However, the industry target is 4 kg per capita. If this goal is achieved, national production would need to increase to 97,200 tonnes, 37% above current levels (Figure 1). Mushroom imports are increasing, whereas exports are minimal and declining (Figure 2).

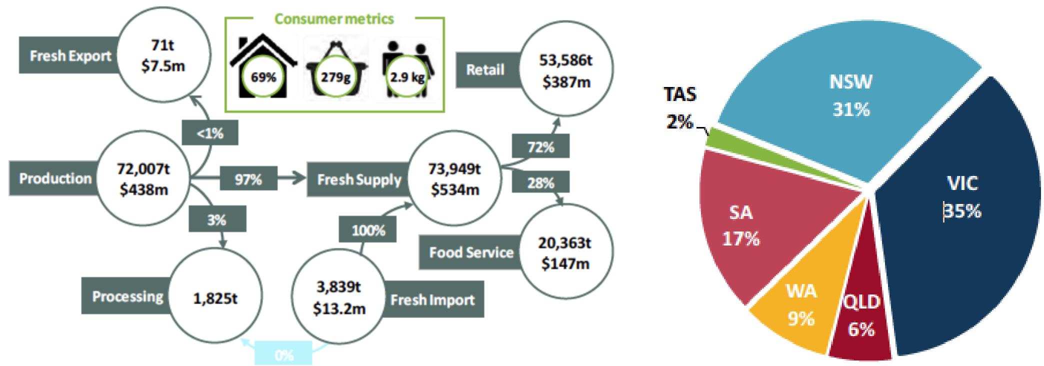

Figure 1. Australian mushroom production by volume, value and supply chain (left), and by state (right). Data compiled by Freshlogic[2]

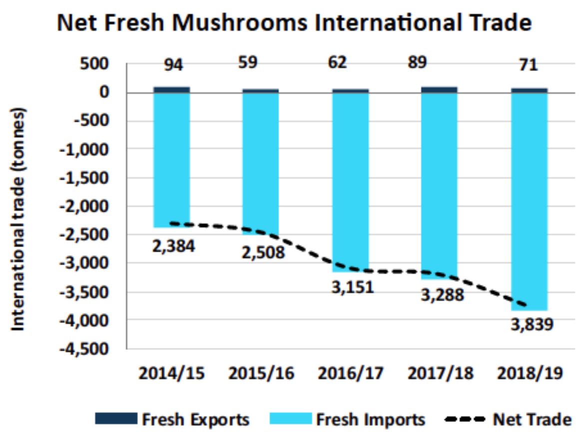

Figure 2. Mushroom exports from Australia[2]

[2] 2018/19 Australian Horticulture Statistics Handbook. Freshlogic and Horticulture Innovation Australia Limited 2020.

3 Methodology

3.1 Desktop review

This desktop review examining the risks and opportunities facing mushroom producers, composters and spawn producers in Australia and internationally to adapt to climate change and mitigate emissions was conducted by accessing the available scientific, grey and other literature.

The source of data used for the review includes:

- International abstracting services including Commonwealth Agricultural Bureau (CAB) abstracts, Biological Abstracts and Current Contents
- *Pre and post-harvest management of mushrooms review*[3] written by Dr Jenny Ekman, AHR
- MU17007 - Substrate Alternatives
- MU18002 - Agri-technology investment in the mushroom industry
- Google Scholar search
- General internet search
- Discussions with industry experts in Australia and overseas.

3.2 Industry consultation

In total, 20 mushroom farms were visited or interviewed via zoom for the project and seven (7) composters were interviewed either face-to-face or by phone using standardised questionnaires. The mushroom farms included three which grow exotic mushrooms, with 7 of the remaining 20 growing both white and brown mushrooms.

According to the Horticulture Statistics Handbook[2], Australia produced 72,000 tonnes mushrooms in 2018-19. Production over 2019-20 is likely to be somewhat lower than this volume, as two large farms in Tasmania and Brisbane have since closed. Participants in this consultation process together produce approximately 51,000 tonnes. This is more than 70% of Australian production and includes all of the major mushroom production facilities.

However, the participants also represent a cross section of the industry. They range in size from Costa's Melbourne facility, with a production of 265 tonnes weekly, which is easily the largest farm in Australia, to small local or niche farms which produce less than a tonne a week.

Many farms are old; only 2 farms were established within the last 10 years, while 9 commenced operating 30 years or more ago. It is notable that four of the six largest producers fell into this category, including Costa's Melbourne, which was originally established in 1976. While many older farms will have been added to, modernized and adapted over the years, it could be expected that it will be harder to adapt relatively old infrastructure to a changing environment.

Many farms are also relatively low technology. The trend overseas has been to shelf operations. These can be efficiently loaded and unloaded, are easier to decontaminate and offer the potential to separate the casing and compost layers at the end of the cropping cycle. However, setup costs are higher than farms using blocks or trays, which may be why only 5 of the surveyed producers were using this system.

[3] Ekman J. 2017. Pre and postharvest management of mushrooms. Final report for Australian mushroom industry advisory panel, funded through Hort Innovation.

Most farms crop for three flushes, although several noted that they may reduce this to two if demand is low or disease becomes an issue.

A summary of key finding from the consultations is outlined below. The full responses are available on a deidentified basis on request.

Table 1 Mushroom farms and composters consulted

Farms			Composters		
	State	**Mushroom production (tonnes/week):**		**State**	**Compost production (tonnes/week)**
1	NSW	53.0	1	NSW	1000
2	NSW	12.5	2	NSW	800
3	NSW	26.5	3	SA	1250
4	NSW	1.0	4	SA	200
5	NSW	28.5	5	VIC	500
6	NSW	75.0	6	VIC	1600
7	NSW	1.5	7	WA	640
8	NSW	3.8	**Total**		**5990**
9	QLD	130.0			
10	QLD	1.8			
11	QLD	22.0			
12	QLD	2.9			
13	QLD	15.0			
14	SA	180.0			
15	SA	42.0			
16	VIC	265.0			
17	VIC	49.0			
18	VIC	2.5			
19	VIC	0.5			
20	WA	76.0			
Total		**988.5**			

4 Key findings from the industry consultation

4.1 Climate Change Action Plan

Farms and composters were asked what they would like to see in a mushroom industry climate change action plan. All composters and almost half of farms would like to see an alternative to straw. Other common responses are shown in Table 2 below.

Table 2. Common topics requested for a mushroom industry climate change action plan

Issue	Farms (%)	Composters (%)	All Industry (%)
Alternative to Straw	47	100	62
Energy Efficiency	42	50	42
Alternative Casing	32	67	38
Water Efficiency	32	50	35
Compost Efficiency	11	33	15

Note: responses from 20 mushroom farms and 7 composters

4.2 Wheat Straw

Most mushroom compost producers source wheat straw locally, when it is available. During the 2018-19 drought, most composters outside Victoria had difficulty sourcing good quality wheat straw. All composters paid more for their straw and transported the straw further. 43% of composters reported they received less mature straw than normal.

Two composters reported increase in disease affecting compost, such as smoky mould, likely due to drier and dustier conditions.

57% of composters considered reusing spent mushroom compost, but none have successfully done so. Risk of disease, economics of transport and effect on yield prevented the successful reuse of spent mushroom compost. All composters said they would like research to be done into alternative carbon sources.

4.3 Energy

Forty five percent (45%) of mushroom farms have photovoltaic solar generation systems installed and another 20% of farms plan on investing in solar. Two compost producers have solar installed and four have solar planned.

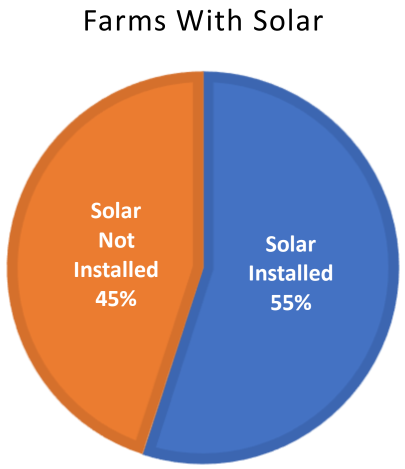

Figure 3. Farms with solar PV installed.

One farm has lead-acid batteries to complement a 100kw solar photovoltaic system, however the payback period was longer than expected and the grower would recommend waiting until battery technology has improved before making the investment.

Another farm had installed an energy recovery ventilation (ERV) system which uses air vented from growing rooms to either pre-heat or pre-cool incoming air through a heat exchanger. The grower reported the system can reduce the cooling or heating load by 5°C without any energy consumption.

The payback period on solar installations as short as two years in Queensland and three to four years in Victoria.

One composter and one farm have behind-the-meter connections, where an external company funded the solar installation and offered the business a reduced electricity tariff.

The mushroom industry is well protected against unstable electricity grids. Half of small mushroom farms (less than 10 tonnes per week) have backup generators installed and 92% of farms producing more than 10 tonnes per week have backup generators installed.

All farms are planning or have already installed LED lighting.

4.4 Casing materials

The industry currently sources peat from Germany, Ireland, the Netherlands, Canada and the Baltic states. Most farms use a 90:10 or 80:20 blend of hard, black peat to blonde (Canadian) peat, although at least three use 100% German black peat.

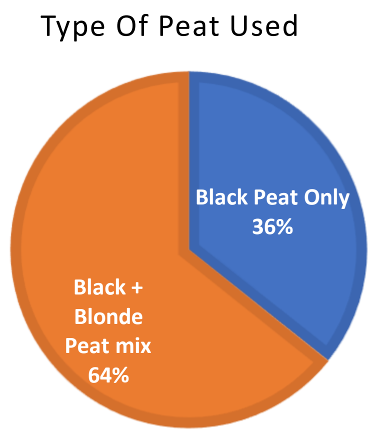

Figure 4. Type of peat used by conventional mushroom farms in Australia

While one respondent claimed the supply of peat from Germany and the Netherlands was guaranteed for the next 50 years, a number of other farms were concerned about ongoing cost and supply. Alternatives that have been trialled include coconut coir, brown coal products, spent barley from breweries, composted green waste and spent diatomaceous earth.

Six farms indicated they were interested in finding alternatives to peat compared to seven that were not, with the remainder undecided. Four farms nominated finding alternatives to peat as a key component of a climate change action plan for the industry.

While peat is a relatively minor cost in mushroom production, there is clear concern regarding the sustainable of use of peat, and potential future interruptions to supply. This was therefore considered to be an important industry vulnerability.

4.5 Water

None of the mushroom farms and one compost producer had water restrictions imposed on them in a recent drought. Two growers had to buy water and have it trucked to their farm in 2019.

All compost producers recycled their runoff water, which is rich in nutrients and inoculating bacteria. Thirty percent (30%) of mushrooms farms recycled their water for cleaning and washdowns.

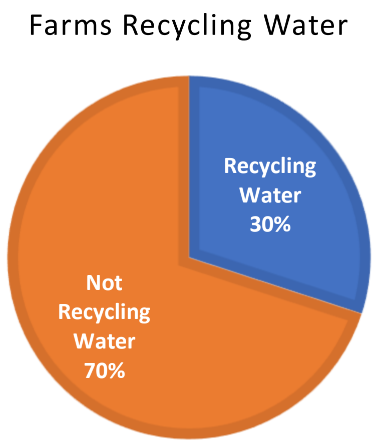

Figure 5. Adoption of water recycling at mushroom farms

Thirty two percent (32%) of farms and 50% of composters requested water efficiency be included in the industry climate change action plan.

Average reported water consumption was 11.9 liters per kilogram of mushrooms. Smaller farms tend to use more water per kilogram of mushrooms and farms with no or limited town supply tend to use less water per kilogram.

To irrigate their crops, 79% of mushroom farms used watering trees and 21% used overhead sprinklers.

4.6 Poultry Manure

All mushroom compost producers use poultry manure, sourced from local farms. There was little effect of drought on the availability of manure, however some poultry farms did switch from rice hulls to sawdust. Two compost producers reported that the cost of poultry manure increased during the drought.

Industry reported that nitrogen content of chicken manure has been steadily decreasing as the poultry industry has developed more efficient feeding methods. Compost producers reported they adjusted their compost formula by adding more nutrients.

5 Climate change science

5.1 Greenhouse gasses and climate

Greenhouses gasses have the effect of capturing some of the heat that radiates from the earth's surface. They therefore have a strong influence on the earth's temperature. The main greenhouse gasses are:

- Water vapor (H_2O)
- Carbon dioxide (CO_2)
- Methane (C_2H_4)
- Nitrous oxide (N_2O)
- Ozone
- Chlorofluorocarbons (CFCs)
- Hydrofluorocarbons (includes HCFCs and HFCs)

The three gasses of most concern in relation to climate change are carbon dioxide, methane and nitrous oxide. Carbon dioxide emissions are mainly from burning fossil fuels, deforestation and agriculture. Methane is emitted by ruminant animals such as cattle and sheep, and also from municipal landfill as well as processing coal and oil. Nitrous oxide is emitted from agricultural soils, especially poorly drained soils where high levels of nitrogen fertilizer were used, burning fossil fuels and water treatment.

Nitrous oxide and methane are more 'intense' greenhouse gasses than carbon dioxide. Nitrous oxide causes about 298 times more warming than CO_2 and methane about 36 times the effect of CO_2[4]. The way that greenhouse gasses affect global temperatures is represented in Figure 3.

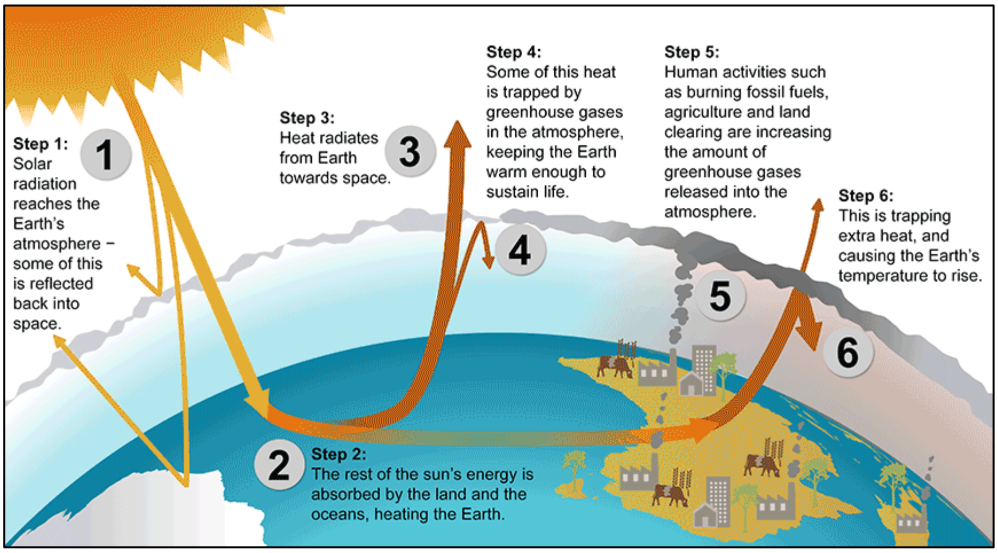

Figure 6. Schematic if the greenhouse effect (Source: Australian Dept of Water and Environment)[5]

[4] US EPA - https://www.epa.gov/ghgemissions/understanding-global-warming-potentials accessed 13/2/2020.

[5] Australian Dept of Water and Environment https://www.environment.gov.au/climate-change/climate-science-data/climate-science/greenhouse-effect

5.2 Global CO_2 levels are rising

Global atmospheric CO_2 levels have risen since pre-industrial times from 280 parts per million (ppm) to a current (2020) level of 413ppm[6]. They are now at a level not seen within the past 800,000 years. The most rapid rise in CO_2 levels has been since the 1960s. Despite global efforts aimed at reducing emissions, the rate of increase in CO_2 has continued to rise for the past 60 years (Figure 7).

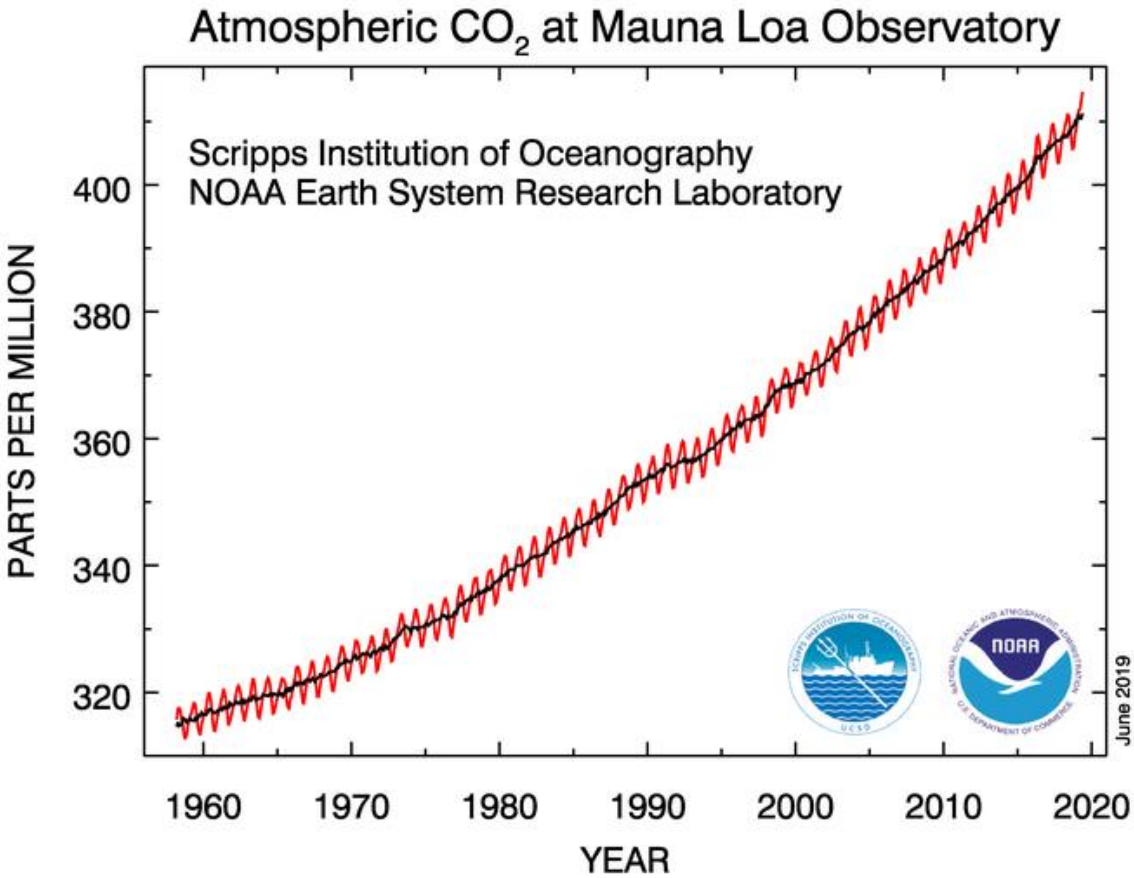

Figure 7. Atmospheric CO_2 levels at Mauna Loa observatory. (Source: NOAA)[7]

When changes in CO_2 are viewed for the past 800,000 years, the sudden increase in the last 60 years is clear. Atmospheric CO_2 levels have not previously exceeded 300 ppm for the whole of that period, despite ice ages as well as periods of warming. The other key greenhouses gasses, methane and nitrous oxide, have shown similar increases in their concentration since industrial times. We are in uncharted waters.

[6] https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html accessed 13/2/2020

[7]National Oceanic and Atmospheric Administration – NOAA https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html accessed 13/2/2020

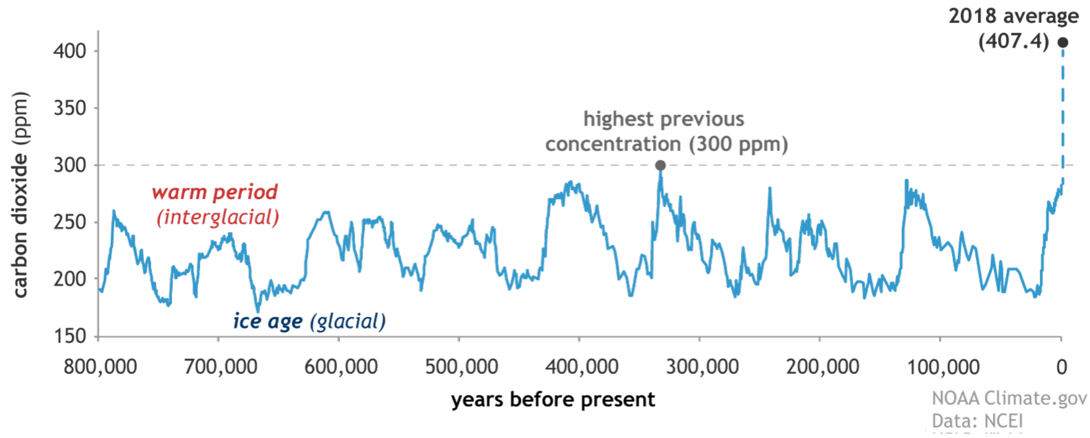

Figure 8. Atmospheric CO_2 levels during ice ages and warm periods over the past 800,000 years. (NOAA)[8]

5.3 Greenhouse gas scenarios

What could happen

The future of the world's climate depends on measures taken to mitigate emissions and how the climate system responds. Models are used to manage this uncertainty by producing a range of climate projections to take account of different scenarios, with their associated greenhouse emission projections. These scenarios range from drastic action to limit emissions to no action at all i.e. business as usual. Figure 9 is a representation of various emissions scenarios and their likely effect on global warming[9].

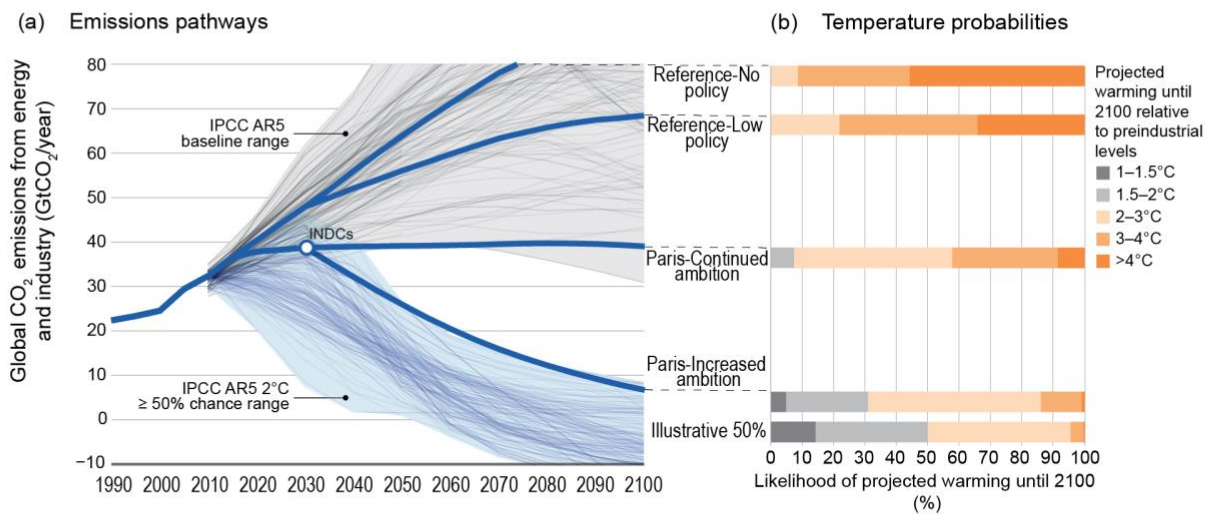

Figure 9. Global CO_2 emissions and probabilistic temperature outcomes of different policies. Source (U.S. Global Change Research Program)[9]

Greenhouse gas scenarios are modelled using Representative Concentration Pathways (RCPs) to explore credible future emissions. These are summarised as:

- RCP 8.5 – Little curbing of emissions, with CO_2 continuing to rise rapidly
- RCP 6.0 – Lower emissions achieved using some mitigation strategies

[8] Lindsey R. 2019. Climate Change: Atmospheric Carbon Dioxide. Climate Watch. NOAA Climate.gov https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide accessed 13/2/2020

[9] U.S. Global Change Research Program: Climate Science Special Report, Fourth National Climate Assessment (NCA4), Volume I, chapter 14.2. https://science2017.globalchange.gov/

- RCP 4.5 – CO_2 emissions slightly higher than RCP 6.0 initially, but peaking around 2040 and then stabilising
- RCP 2.6 – Active curbing of emissions including actively removing CO_2 from the atmosphere, with the result that emissions peak around 2020 but then rapidly decline.

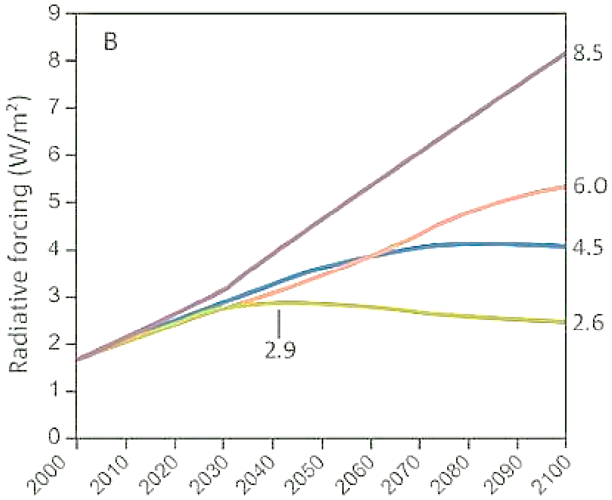

Figure 10. Predicted atmospheric CO_2 levels by 2100 (Source: Climate change in Australia Technical Report.)

The changes in climate observed in the last 50 years are projected to continue and accelerate. By 2070, average Australian temperatures are projected to increase by about 1.8°C in a low emissions scenario, with a range of 1.0-2.5°C across the country. If emissions remain high, the projected average temperature increase is about 3.4°C, with a range of 2.2-5.0°C, relative to 1990.

In south-eastern Australia, El Niño events will become drier and La Niña events may become wetter[10]. For 2035, rainfall is projected to decrease by 2-5% on average, and by about 7.5% by 2070 (compared to 1990). The exception is far northern Australia where little rainfall change is projected. However, changes in rainfall are expected to vary widely across regions and seasons. For example, rainfall in south-western Australia is projected to decline by as much as 40% by 2070.

These changes will impact on investments and natural resource decisions made this decade – for example, investment in irrigation infrastructure, biodiversity plantings and water management.

Climate modelling

The modelling component of this project used the **Australian Climate Futures** model[11] to predict climate impacts for three GHG emission scenarios; low (RCP 2.6), medium (RCP 4.5) and high (RCP 8.5). The Australian Climate Futures model is a flexible, multi-purpose decision-support tool to assist understanding and application of climate change projections for impact assessment and adaptation planning.

5.4 Climate variability

Regional climates can vary greatly from year to year. This short-term variability is the result of the regional atmospheric circulation features summarised in Figure 11 [12]. Best known is the El Niño, which is the warm phase of the El- Niño -Southern Oscillation (ENSO). During an El Niño year, a band

[10] CSIRO 2007. Climate change in Australia – observed changes and projections CSIRO and Bureau of Meteorology.

[11] https://www.climatechangeinaustralia.gov.au/en/ accessed 13/2/2020

[12] Bureau of Meteorology, Commonwealth of Australia, http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml?bookmark=introduction. Accessed 19/3/2013.

of warm water develops in the eastern Pacific to South America. The result is high pressure over eastern Australia and lower than average rainfall. El Niño conditions generally occur every 3-8 years. The cool phase of ENSO is La Niña, which tends to increase rainfall in Australia. It is unclear whether climate change will change the strength or frequency of El Niño events[13].

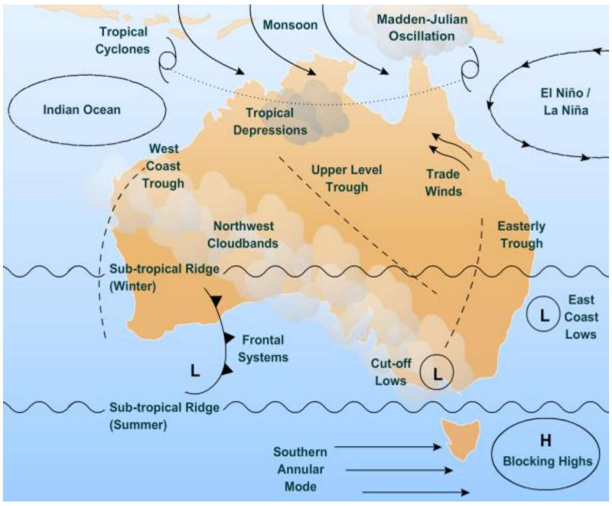

Figure 11. The family of circulation features responsible for much of Australia's climate variability. Source: CSIRO and BOM.

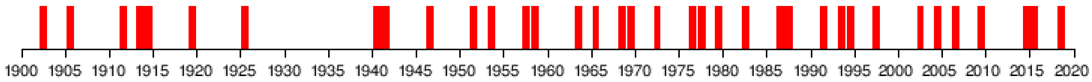

Figure 12. Timeline of El Niño episodes between 1900 and 2019[14].

Understanding how these features operate and influence the weather in different regions is progressing rapidly. Rain-fed agriculture is increasingly using this to assist decision-making.

It is through these circulation features that the longer-term climate change plays out. For example, the autumn-winter rainfall declines in south-west WA, and more recently in Victoria, are associated with a range of other variations, all of which are inter-related and forced by the same mechanisms[15]. These changes are consistent with those predicted by anthropogenic climate change. Excellent short videos of the key circulation features that drive climate variability can be found at "The Climatedogs"[16]. However, as Figure 12 highlights, climate is complicated and the Australian environment is hard to predict.

[13] Di Liberto T. 2014. NOAA www.climate.gov/news-features/blogs/enso/enso-climate-change-headache

[14] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

[15] Bradley Murphy & Bertrand Timbal 2008. A review of recent climate variability and climate change in southeastern Australia. International Journal of Climatology 28: 859–879.

[16] "The Climatedogs" http://www.dpi.vic.gov.au/agriculture/farming-management/weather-climate/understanding-weather-and-climate/climatedogs.

6 Changes that have already occurred in Australia

6.1 Introduction

In the past 50 years the Australian climate has changed significantly. Average temperatures have increased by about 1°C, rainfall has increased over northwest Australia while eastern and south-western Australia have become drier, and the frequency and intensity of extreme weather events have increased markedly.

Australia experienced its worst bushfire season on record in summer 2019/20. Fires burnt an estimated 18.6 million hectares or 186,000 square kilometres (equivalent to 3 times the area of Tasmania), destroyed more than 5,900 buildings (including 2,779 homes)[17] and killed at least 34 people [18].

Rainfall across eastern Australia, following these bushfires, extinguished most of the fires but dumped 392 mm of rain on Sydney in four days, just under half the entire 2019 rainfall of 851 mm for the region[19].

These tragic events may be a turning point for action on climate impacts of greenhouses gasses and energy, so policy settings may change significantly in the near future. They are a timely reminder that our climate is now changing rapidly. Unless greenhouse gas emissions can be drastically reduced, the changes will continue as predicted.

6.2 Air and sea temperature

The 2018 State of the Climate[20] report states that Australia's climate has warmed by just above 1°C since national records began in 1910, especially since 1950. This is graphically illustrated by the Bureau of Meteorology chart showing the annual deviation from long term mean temperatures across Australia (Figure 14). This clearly shows that 2019 was the hottest year on record. Sea temperatures have also risen, resulting in the third mass bleaching event of the Great Barrier reef in five years, with 60% of reefs now affected[21]. Coral bleaching was recorded for the first time in 1997 but has since increased in severity and frequency.

The long-term trend in temperature is clear, but there is still substantial year-to-year variability of about ±0.5 °C. Some areas have experienced a warming of 1.5 to 2°C in the last 50 years. Warming has occurred in all seasons, but the strongest warming has occurred in spring (about 0.9°C) and the weakest in summer (about 0.4°C)[20].

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[17] Tiernan F, O'Mallon E. 2020. "Australia's 2019-20 bushfire season". The Canberra Times. Retrieved 13 January 2020.

[18] Wikipedia https://en.wikipedia.org/wiki/2019%E2%80%9320_Australian_bushfire_season#cite_note-:14-11 accessed 12 February 2020.

[19] https://www.abc.net.au/news/2020-02-10/sydney-wet-weather-means-warragamba-dam-levels-to-surge/11948812 retrieved 12th February 2020

[20] CSIRO and BOM. 2018. State of the Climate report. Commonwealth of Australia http://www.bom.gov.au/state-of-the-climate/

[21] Slezak M. Timms P. 2020. https://www.abc.net.au/news/2020-04-07/great-barrier-reef-most-widespread-coral-bleaching-on-record/12107054

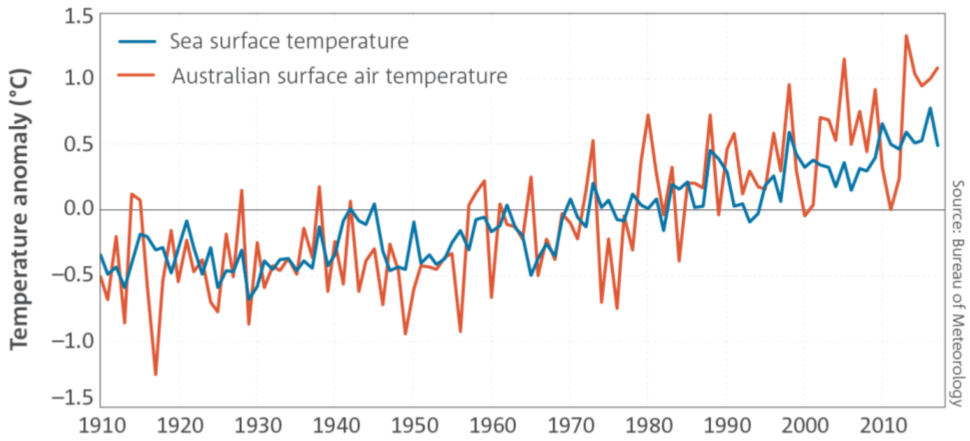

Figure 13. Average air and sea temperature rise since 1910. Source: State of the Climate report 2018[20].

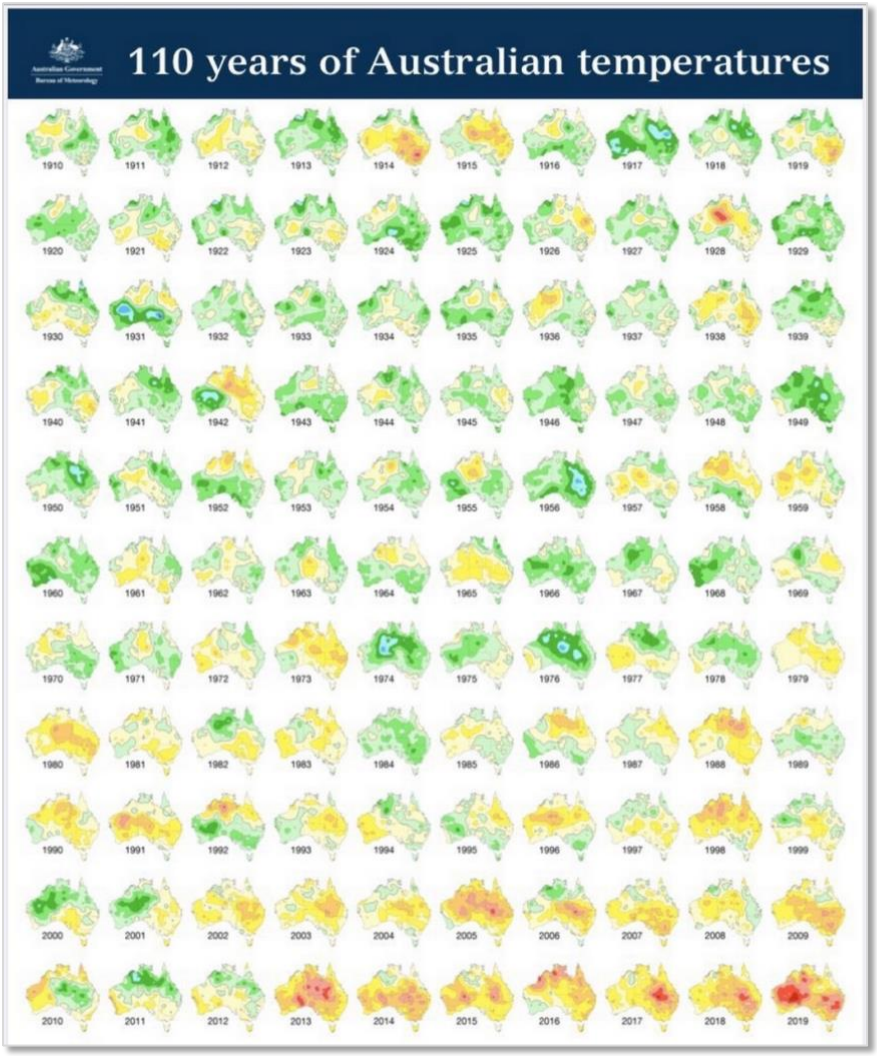

Figure 14. Annual deviations from long term average temperatures. Colours range from dark blue (>3°C below average) to cream (average) to red-brown (>3°C above average). Source: Bureau of Meteorology[22].

[22] BOM. 2020. 110 years of Australian temperatures. http://www.bom.gov.au/climate/history/temperature/

6.3 Rainfall

Rainfall has increased over northwest Australia while eastern and south-western Australia has become drier. Rainfall has decreased in the southwest of Australia by about 20% since 1970. In south-eastern Australia, average rainfall has declined by about 11% for the same period. In northern Australia, rainfall has increased since the 1970s (Figure 15)[20].

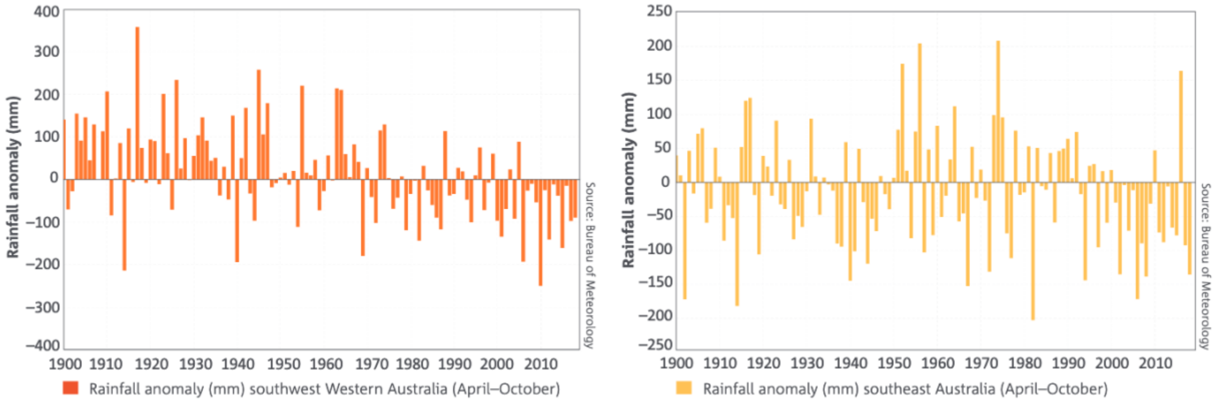

Figure 15. Average rainfall changes in southwestern and south-eastern Australia since 1900. Source: State of the Climate report[20].

6.4 Extreme weather events

The climate is now more variable. There are fewer cold days and nights and more hot days, hot nights and more heatwaves (Figure 16). The intensity of storms has increased and heavy rainfall events have increased in frequency. The risk of frost has increased along with more volatile weather patterns. Even though the climate is warmer overall, cold extremes are more intense, meaning the frost window has widened[23].

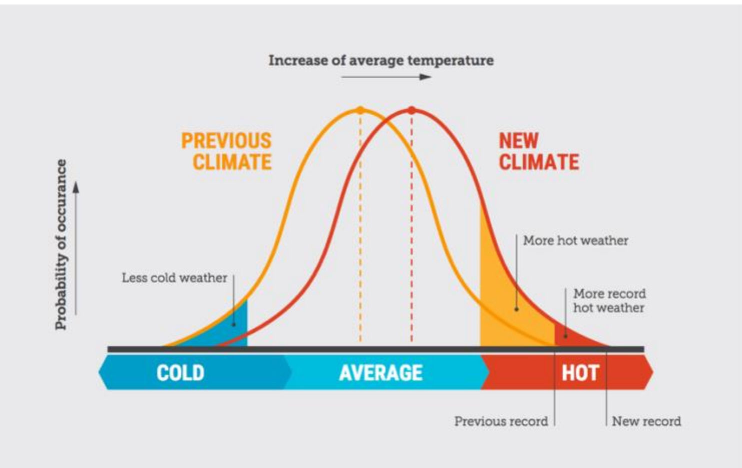

Figure 16. Schematic showing the increased probability of hot extremes and decreased probability of cold extremes with an increase in average temperatures. Source: Climate council[23].

The increase in extreme weather events is likely to have a significant effect on the mushroom industry now and in the immediate future.

[23] Climate council of Aust. 2019. Weather gone wild: Climate change fueled extreme weather in 2018. https://www.climatecouncil.org.au/wp-content/uploads/2019/02/Climate-council-extreme-weather-report.pdf

Extreme events will have unpredictable effects on the availability of input supplies such as wheat straw, transport, inputs and sales. It is also likely to place extreme demands on the cooling systems for controlling growing room temperatures as temperature extremes become more common.

Heatwave example – Sydney 2020

A good example of these extremes occurred in Sydney in January 2020. The maximum temperature at Penrith, NSW reached 48.9°C on 4 January (Figure 17), its hottest day on record, making it one of the hottest places on earth and setting a new temperature record for the Sydney basin[24].

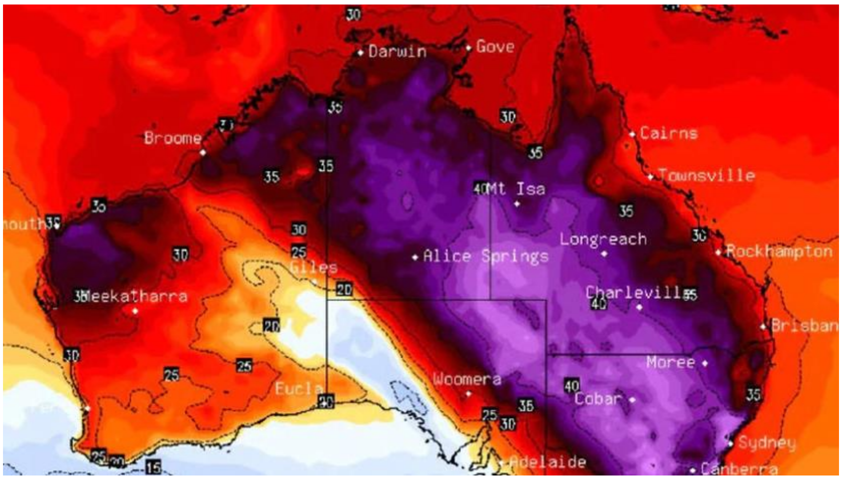

Figure 17. Penrith was the hottest place on Earth on Saturday 4th January 2020, reaching a high of 48.9C. Source: SBS News 04/04/2020

[24] https://www.smh.com.au/environment/weather/hottest-place-on-the-planet-penrith-in-sydney-s-west-tops-48-degrees-20200104-p53osu.html accessed 12th February 2020.

7 Predicted future changes in the Australian climate

7.1 Introduction

There have been many studies predicting local and global impacts of climate changes caused by greenhouse gas emissions. The science is well established, and the International Intergovernmental Panel on Climate Change (IPCC) reviews the science and produces regular consolidated synthesis reports of the current science and predictions. The most recent report was published in 2014 and the next report is due in 2022[25].

The Climate Council of Australia[26] summarizes the science for Australia and makes local predictions of what may occur given particular climate change scenarios and greenhouse gas emissions. A good example is *This Is What Climate Change Looks Like*[27] which paints the picture of predicted changes in Australia.

Applied Horticultural Research undertook a detailed study of the likely effects of climate change for the Australian vegetable industry in 2013. This study modelled the predicted climate changes in six vegetable growing regions around Australia to 2035 using a robust methodology involving several models and greenhouse gas abatement scenarios. The results are summarized in a report and the website www.vegetableclimate.com.au[28].

The outcomes from this study also provide indications of likely changes in climate affecting mushroom growing and compost-producing regions. The table below from the AHR vegetable industry study shows predicted temperature and rainfall, and how the frequency of heat waves will increase. It is the frequency of heat waves and droughts which is the most concerning, and most likely to impact the mushroom industry.

Table 3. Regional climate predictions for 2035

Region	Average temperature	1:10 year max (February)	Rainfall
Gatton	+ 1.1	+ 3.1	- 3%
Hay	+ 1.1	+ 4.1	- 5%
Werribee	+ 1.0	+ 3.5	- 8%
Murray Bridge	+ 0.9	+ 3.8	- 8%
Manjimup	+ 0.8	+ 2.8	- 7%*
Devonport	+ 0.6	+ 1.7	- 6%

[25] https://www.ipcc.ch

[26] https://www.climatecouncil.org.au/

[27] Hughes L, Dean A., Steffen W., Rice M. 2019. This is what climate change looks like. Climate Council of Australia.

[28] Rogers G, Montagu K. 2015. Understanding and managing the impacts of climate on the Australian vegetable industry. Horticulture Australia report from projects VG12041 and VG12049.

Table 4. Risk of extreme events will increase

Region	Risk of 3-5 days over 40°C	
	Now	2035
Gatton	1 year in 33	1 year in 10
Hay	1 year in 5	Every second year
Werribee	1 year in 5	Every second year
Murray Bridge	1 year in 5	1 year in 3
Manjimup	never	1 year in 5
Devonport	never	never

Droughts in the eastern states are expected to increase by 20% by 2030 from 2004 levels[29], which will disrupt the supply of quality straw for mushroom compost.

7.2 Methodology

The **Australian Climate Futures** model[30] was used to model climate impacts for three GHG emission scenarios; low (RCP 2.6) medium (RCP 4.5) and high (RCP 8.5). The Australian Climate Futures model is a flexible, multi-purpose decision-support tool to assist understanding and application of climate change projections for impact assessment and adaptation planning. AHR used this model for the vegetable climate change modelling work.[31]

The model is built on CSIRO's robust Representative Climate Futures Framework and includes projections from global and regional climate models as well as statistically downscaled results. The model can predict to year 2090 using up to four scenarios of greenhouse gas concentrations (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5). It can produce up to 40 simulations and predict up to 16 climate variables[32].

The focus areas used in setting up the model included:

- **Straw supplies**: Impact of temperature (max, min, average), rainfall, extreme weather events and droughts on wheat straw-growing regions and for outdoor compost making
- **Compost production**: temperature (max, min, average), rainfall, heat waves
- **Wind and solar power generation**: Wind speeds and solar radiation for power generation
- **Pest and diseases**: Temperature, relative humidity, wind speed on pests and diseases
- **Heating and cooling requirements of growing rooms**: temperature (max, min, average)

The following six regions were covered by the modelling of predicted climate changes by 2070:

- Sydney and the Hunter Valley, NSW
- Brisbane, Queensland
- Perth, Western Australia
- Mildura and Melbourne, Victoria
- Hobart, Tasmania
- Adelaide, South Australia

[29] Mpelasoka, F., Hennessy, K., Jones, R. and Bates, B. 2008. Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management. Int. J. Climatology, 28(10), pp.1283-1292.

[30] https://www.climatechangeinaustralia.gov.au/en/ accessed 13/2/2020

[31] Rogers, G. 2013. Understanding and managing impacts of climate change and variability on vegetable industry productivity and profits VG12041 Hort Innovation Final Report

[32] Australian Climate Futures https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/introduction-climate-futures/

7.3 Predicted climate changes

Below are the potential changes in annual climate are provided for 30 (2050) and 50 years from today. These are not predictions of what the climate will be like, but provide an indication of potential future climates depending on how Australia and the rest of the world responds to the challenge of reducing greenhouse emissions. Currently, global emissions are tracking on the most extreme scenario (RCP 8.5).

In addition, the potential climate extremes are provided for the hottest day and coldest night. These “unpack” the annual averages and provide an indication of what potential changes in extremes could occur in 30 and 50 years under the two scenarios.

Brisbane, Queensland

Temperature values are the change in °C. For all other parameters results are given as a change in % and direction to provide an indication of the direction and magnitude of any changes. 2050 is the average for 2040-2059, 2070 is the average for 2060-2079 (Table 5).

Table 5. Summary of the potential changes in annual climate averages for South East Queensland under a moderate (RCP 4.5) and high (RCP 8.5) emissions scenario

			RCP4.5		RCP8.5	
	Period	1981-2005	2050	2070	2050	2070
Annual climate variable			*°C change from 1981-2005 average*			
Temperature	Maximum *(°C)*	27.1	1.5	2.1	2.0	2.4
	Minimum *(°C)*	13.8	1.3	1.7	1.6	2.4
			% change from 1981-2005 average			
Rainfall *(mm)*		1,044	-12	-28	-19.4	-12.4
Relative Humidity *(%)*		51	-4.3	-9.8	-4.3	-2.1
Solar radiation *(MJ m^{-2})*		19	1.8	5.0	2.7	1.0
Wind speed *(km hr^{-1})*		12	-0.1	1.5	1.7	1.7

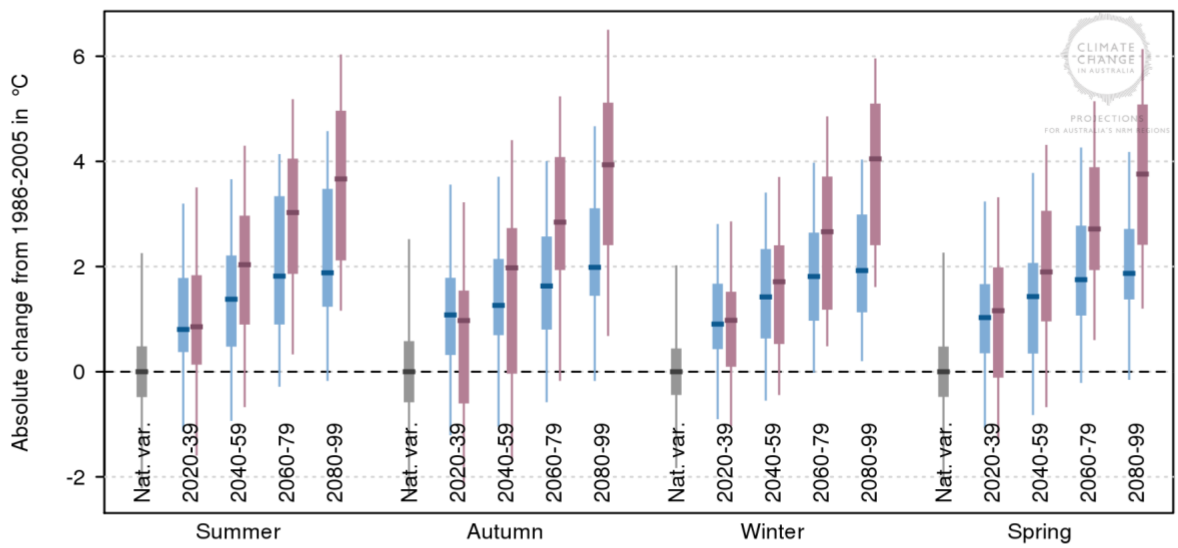

Figure 18. The potential changes in the hottest day (°C) for South East Queensland under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 18).

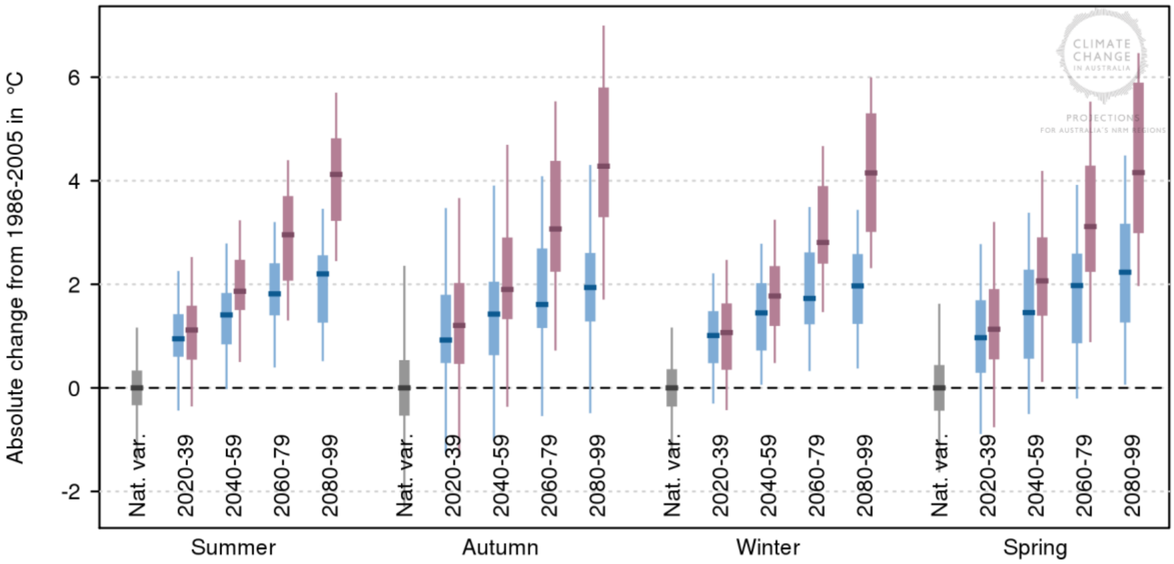

Figure 19. The potential changes in the coldest night (°C) for South East Queensland under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 19).

Sydney & Hunter Valley, NSW

Temperature values are the change in °C. For all other parameters results are given as a change in % and direction to provide an indication of the direction and magnitude of any changes. 2050 is the average for 2040-2059, 2070 is the average for 2060-2079 (Table 6).

Table 6. Summary of the potential changes in annual climate averages for Sydney and the Hunter valley under a moderate (RCP4.5) and high (RCP8.5) emissions scenario.

	Greenhouse gas scenarios		RCP4.5		RCP8.5	
	Period	1981-2005	2050	2070	2050	2070
Annual climate variable			*°C change from 1981-2005 average*			
Temperature	Maximum (*°C*)	23.8	1.5	2.1	1.9	2.6
	Minimum (*°C*)	11.2	1.3	1.7	1.5	2.2
			% change from 1981-2005 average			
Rainfall *(mm)*		832	-6.8	-28	-14	-19
Relative Humidity *(%)*		49	-0.8	-9.8	-2.7	-4.7
Solar radiation *(MJ m^{-2})*		21	0.8	5.0	3.6	3.7
Wind speed *(km hr^{-1})*			-1.8	1.5	-1.4	3.6

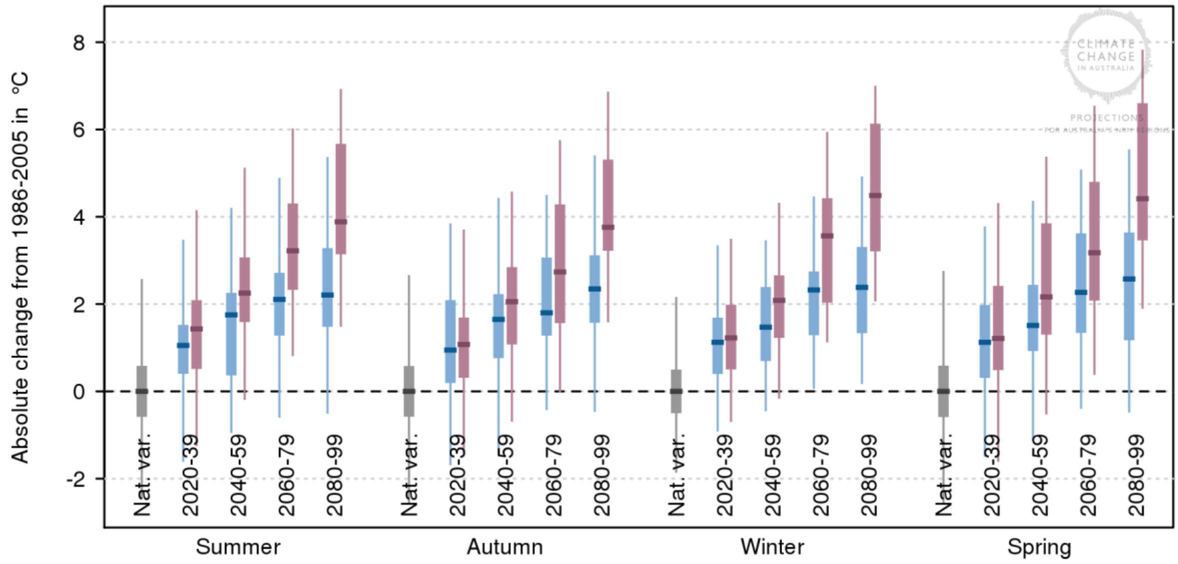

Figure 20. The potential changes in the hottest day (°C) for Sydney and the Hunter valley under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 20).

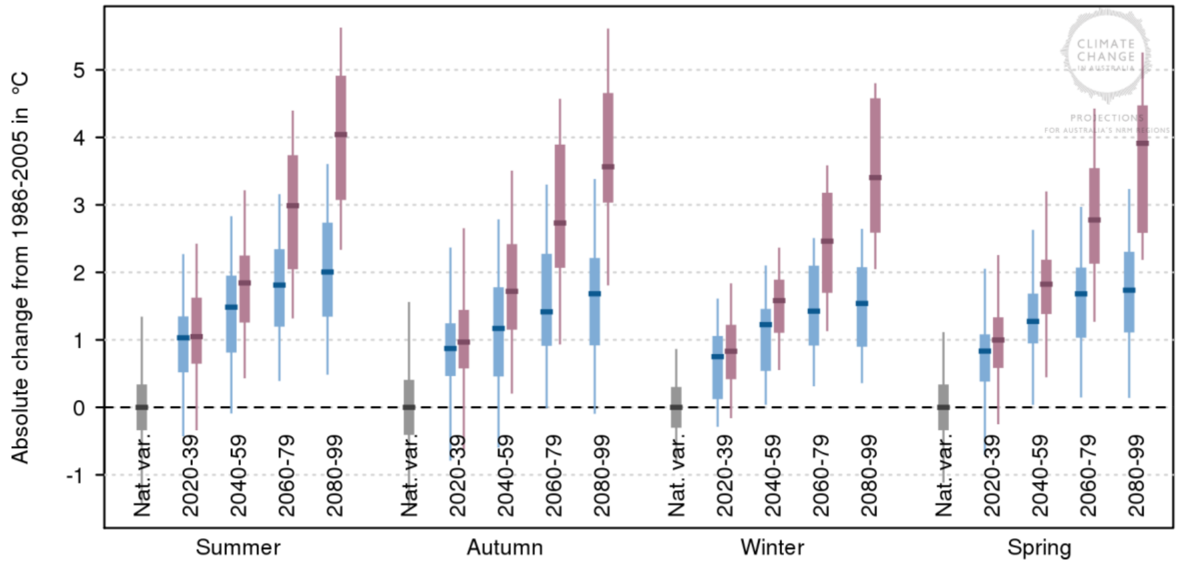

Figure 21. The potential changes in the coldest night (°C) for Sydney and the Hunter valley under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 21).

Mildura, Victoria

Temperature values are the change in °C. For all other parameters results are given as a change in % and direction to provide an indication of the direction and magnitude of any changes. 2050 is the average for 2040-2059, 2070 is the average for 2060-2079 (Table 7).

Table 7. Summary of the potential changes in annual climate averages for the Mildura region under a moderate (RCP4.5) and high (RCP8.5) emissions scenario.

	Greenhouse gas scenarios		RCP4.5		RCP8.5	
	Period	1981-2005	2050	2070	2050	2070
Annual climate variable			*°C change from 1981-2005 average*			
Temperature	Maximum *(°C)*	24.0	1.4	1.4	2.2	2.8
	Minimum *(°C)*	10.3	0.8	1.2	1.7	2.2
			% change from 1981-2005 average			
Rainfall *(mm)*		272	-12	-33	-13	-27
Relative Humidity *(%)*		37	-1.2	-1.7	-5.4	-11
Solar radiation *(MJ m^{-2})*		19	2.2	2.7	2.7	3.8
Wind speed *(km hr^{-1})*		18	0.1	-2.0	1.0	1.4

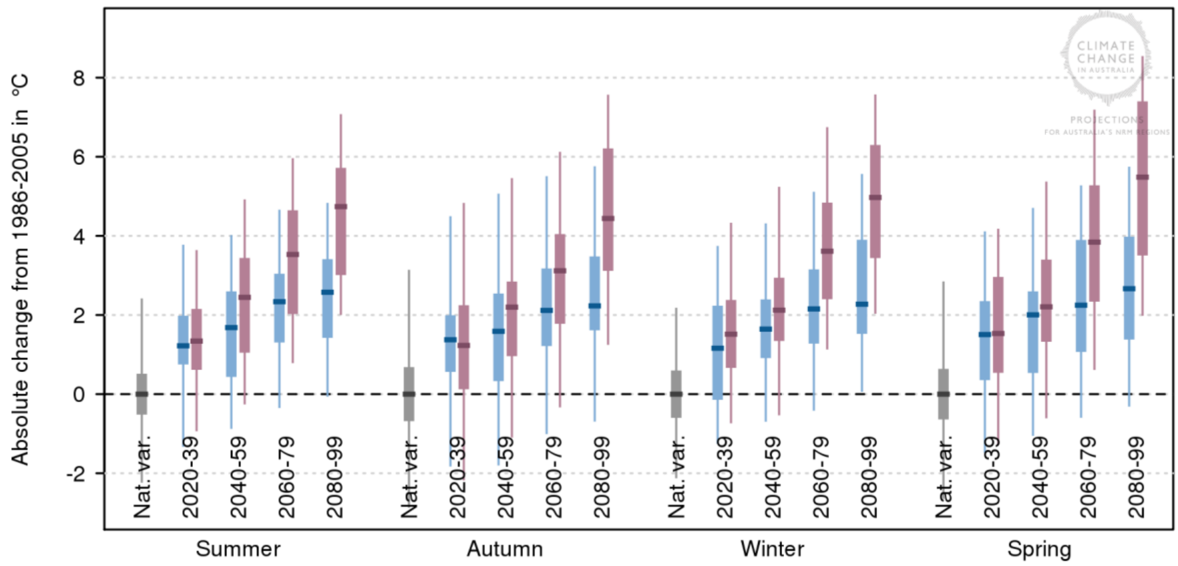

Figure 22. The potential changes in the hottest day (°C) for the Mildura region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 22).

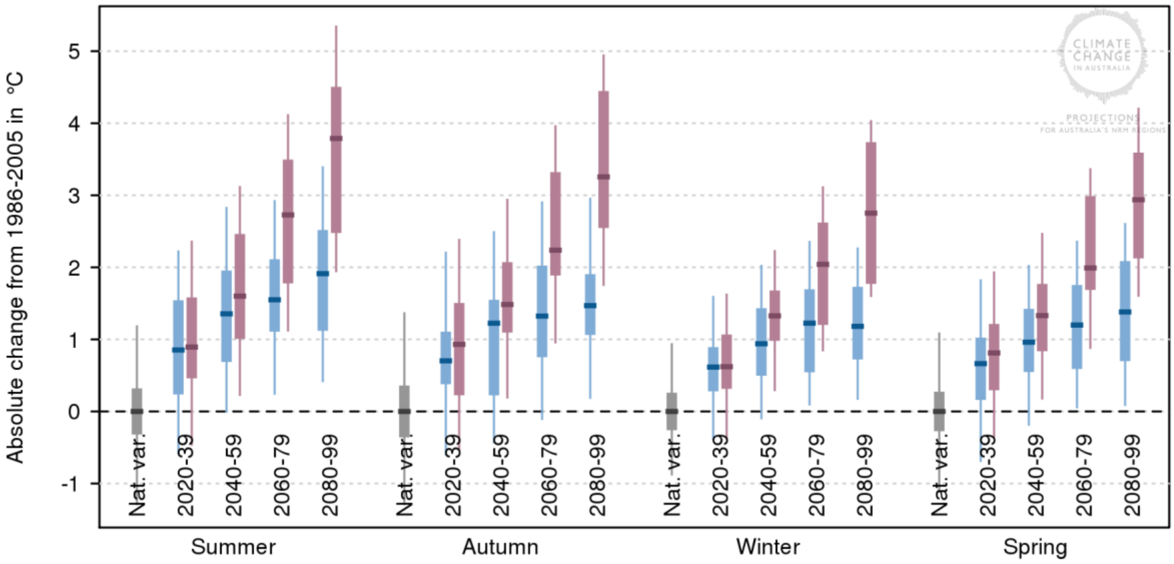

Figure 23. The potential changes in the coldest night (°C) for the Mildura region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 23).

Melbourne, Victoria

Temperature values are the change in °C. For all other parameters results are given as a change in % and direction to provide an indication of the direction and magnitude of any changes. 2050 is the average for 2040-2059, 2070 is the average for 2060-2079 (Table 8).

Table 8. Summary of the potential changes in annual climate averages for the Melbourne region under a moderate (RCP4.5) and high (RCP8.5) emissions scenario.

	Greenhouse gas scenarios		RCP4.5		RCP8.5	
	Period	1981-2005	2050	2070	2050	2070
Climate variable			*°C change from 1981-2005 average*			
Temperature	Maximum *(°C)*	19.8	1.1	1.6	1.3	2.2
	Minimum *(°C)*	9.6	0.7	1.0	1.0	1.8
			% change from 1981-2005 average			
Rainfall *(mm)*		518	-11	-25	-14.9	-25
Relative Humidity *(%)*		52	-3.0	-7.0	-4.3	-7.0
Solar radiation *(MJ m^{-2})*		15	1.4	3.3	2.0	3.0
Wind speed *(km hr^{-1})*		22	-0.7	-1.4	1.5	0.5

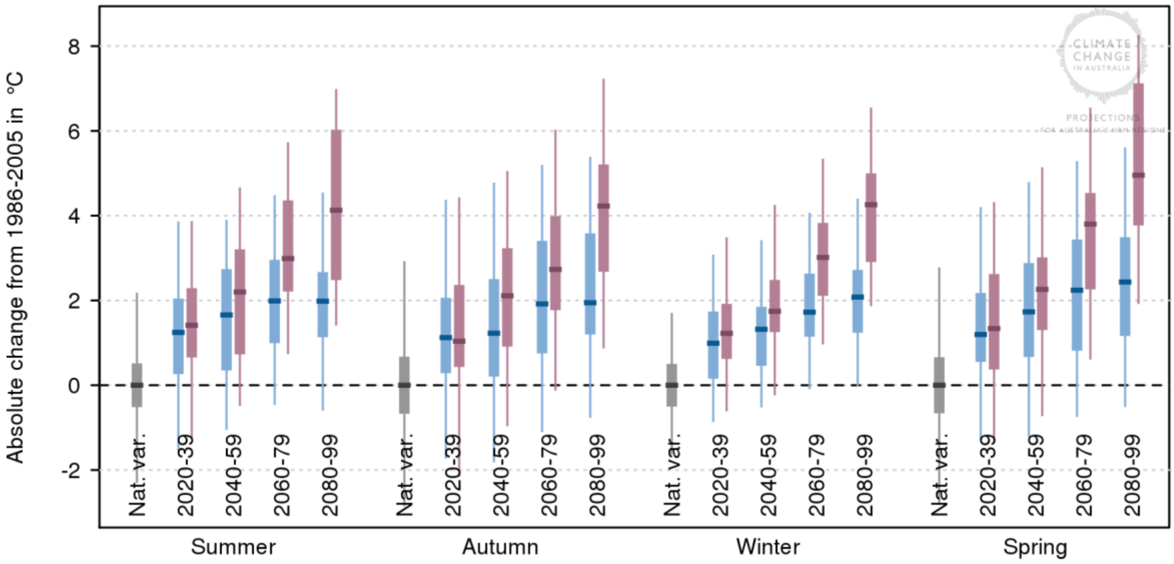

Figure 24. The potential changes in the hottest day (°C) for the Melbourne region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 24).

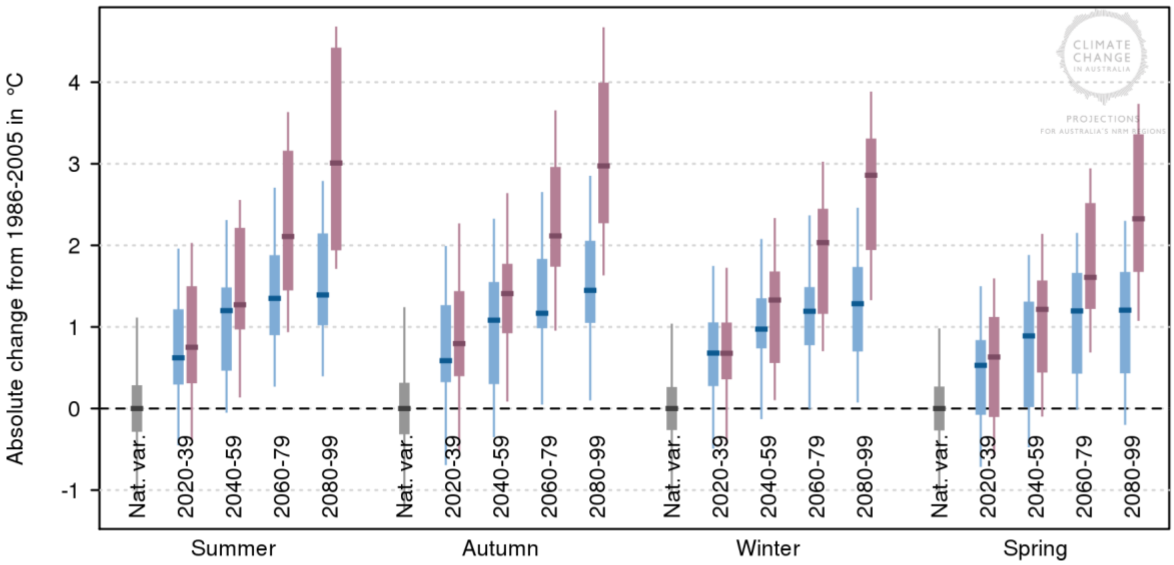

Figure 25. The potential changes in the coldest night (°C) for the Melbourne region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 25).

Adelaide, South Australia

Temperature values are the change in °C. For all other parameters results are given as a change in % and direction to provide an indication of the direction and magnitude of any changes. 2050 is the average for 2040-2059, 2070 is the average for 2060-2079 (Table 9).

Table 9. Summary of the potential changes in annual climate averages for the Adelaide region under a moderate (RCP4.5) and high (RCP8.5) emissions scenario.

	Greenhouse gas scenarios		RCP4.5		RCP8.5	
	Period	1981-2005	2050	2070	2050	2070
Climate variable			*°C change from 1981-2005 average*			
Temperature	Maximum *(°C)*	22.8	1.6	1.6	1.9	2.6
	Minimum *(°C)*	10.0	1.3	1.3	1.7	2.3
			% change from 1981-2005 average			
Rainfall *(mm)*		483	-16	-35	-22	-24
Relative Humidity *(%)*		50	-1.6	-8.2	-2.1	-1.7
Solar radiation *(MJ m^{-2})*		18	0.7	3.7	0.5	0.9
Wind speed *(km hr^{-1})*		11	-0.7	2.0	1.2	0.9

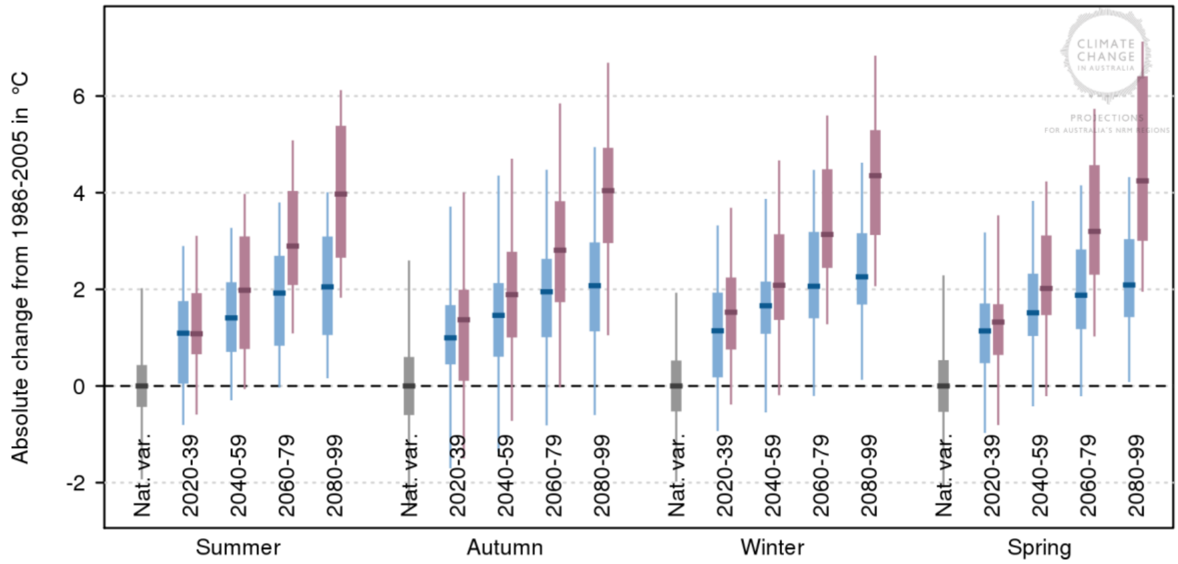

Figure 26. The potential changes in the hottest day (°C) for the Adelaide region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 26).

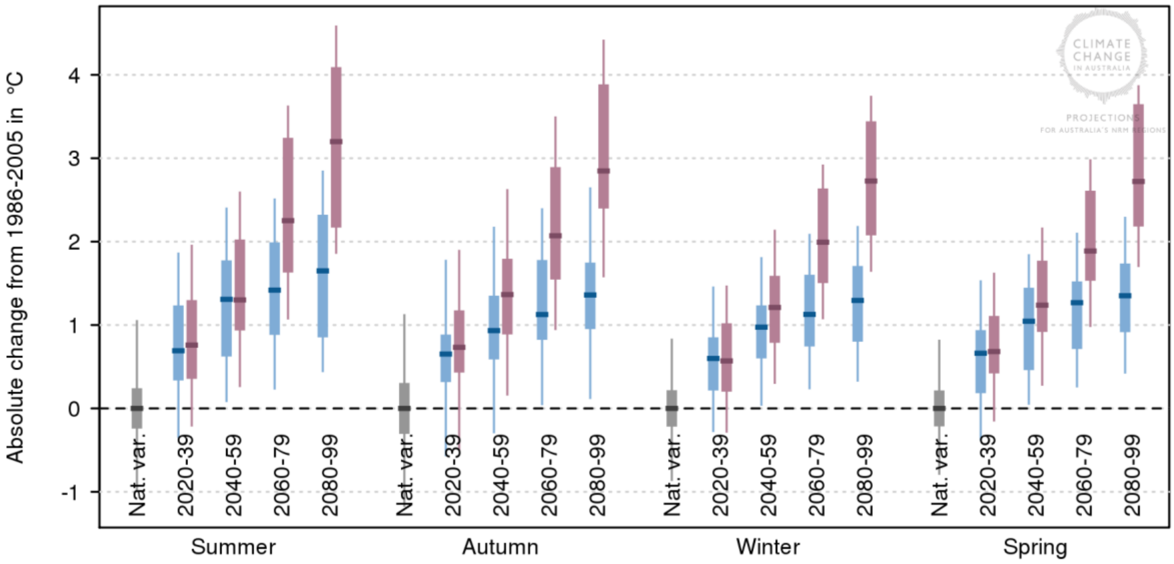

Figure 27. The potential changes in the coldest night (°C) for the Adelaide region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 27).

Perth, Western Australia

Temperature values are the change in °C. For all other parameters results are given as a change in % and direction to provide an indication of the direction and magnitude of any changes. 2050 is the average for 2040-2059, 2070 is the average for 2060-2079 (Table 10).

Table 10. Summary of the potential changes in annual climate averages for the Perth region under a moderate (RCP4.5) and high (RCP8.5) emissions scenario.

	Greenhouse gas scenarios		RCP4.5		RCP8.5	
	Period	1981-2005	2050	2070	2050	2070
Climate variable			*°C change from 1981-2005 average*			
Temperature	Maximum *(°C)*	24.6	1.1	1.8	2.0	2.2
	Minimum *(°C)*	12.4	0.7	1.7	1.5	1.8
			% change from 1981-2005 average			
Rainfall *(mm)*		725	-19	-23	-25	-27
Relative Humidity *(%)*		45	-4.4	-4.2	-4.9	-6.0
Solar radiation *(MJ m^{-2})*		19	1.3	1.9	2.2	1.3
Wind speed *(km hr^{-1})*		20	0.7	-0.3	2.4	2.8

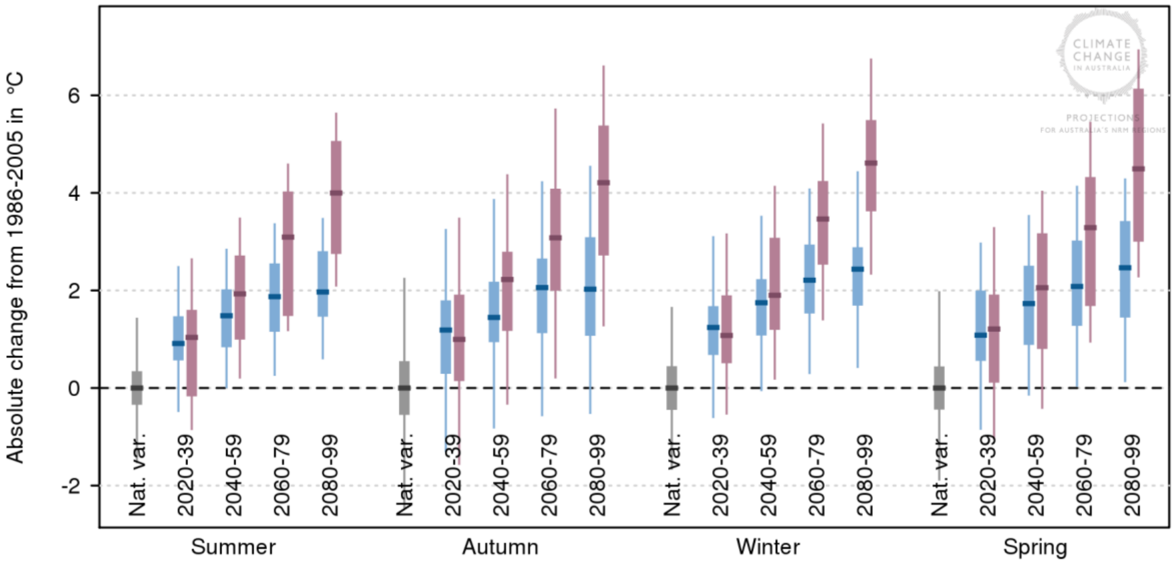

Figure 28. The potential changes in the hottest day (°C) for the Perth region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 28).

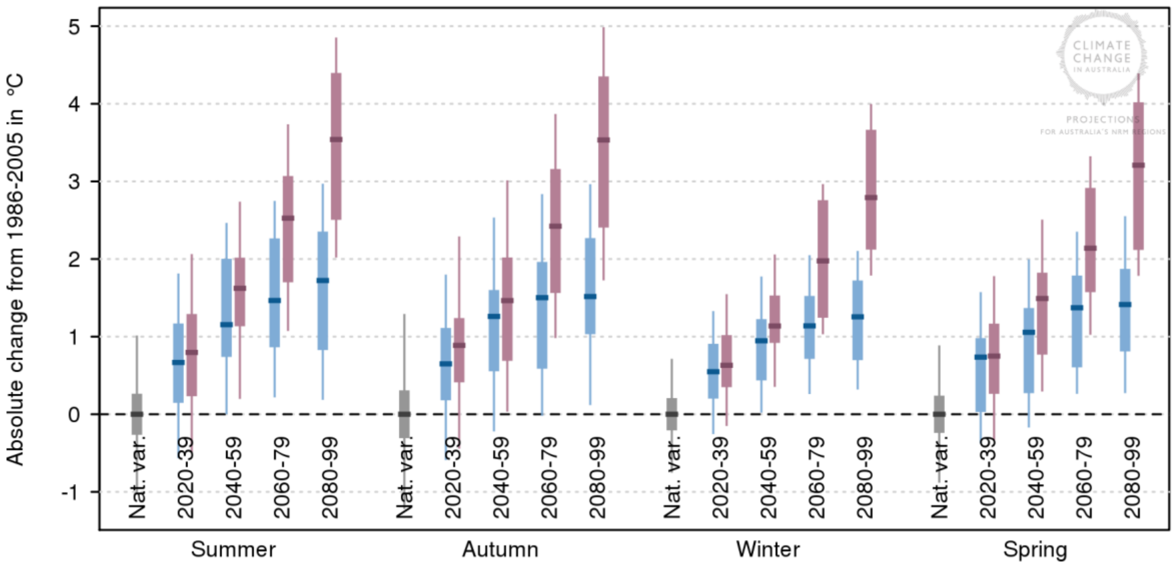

Figure 29. The potential changes in the coldest night (°C) for the Perth region under a moderate (RCP 4.5, blue) and high (RCP 8.5, red) emissions scenario in the four seasons.

The middle (bold) line is the median value of the model simulations (20-year moving average climate); The bars show the range (10th to 90th percentile), and the vertical line show projected range (10th to 90th percentile) of individual years taking into account year-to-year variability in addition to the long-term response (Figure 28).

7.4 Weather variability

Prediction of extreme weather events and climate variability is challenging. I It is not currently possible to predict with any confidence the precise variability in temperature for Australia's mushroom growing areas. Frustratingly, it is temperature variability, especially high and low temperature spikes, which is vital to producers for their short and longer-term planning.

Table 11 shows how projections of broad-scale trends in climate are most likely to play out as changes in the annual number of hot days (>35°C). While the number of hot days will increase in all regions, the effects are not the same in all areas. For example, while the number of hot days in Richmond, west of Sydney, is expected to increase by 50%, Hobart shows little change[33].

Table 11. Average number of days above 35°C

Region	Present average (1981–2010)	Last year (1/5/19 to 30/4/20)	2030 average (low emissions) RCP 4.5	2030 average (high emissions) RCP 8.5	2050 average (low emissions) RCP 4.5
Sydney	4.9	6	7.2	7.8	8.8
Richmond	14.2	27	19.7	20.9	22.7
Melbourne	8.3	11	11.6	11.8	12.8
Mildura	35.9	41	44.7	46.4	49.2
Brisbane	1.8	5	3.4	4.2	5.1
Adelaide	17.1	16	21.9	22.2	23.7
Perth	16.9	37	23.2	23.0	26.1
Cairns	3.9	6	7.6	9.1	11.9
Hobart	0.7	4	1.0	1.0	1.3

Source: Climate change in Australia – Projections for NRM regions

7.5 Rising temperatures

CSIRO and the Bureau of Meteorology have considered the implications of a 4°C increase in average global temperature for Australia. While targets are being set to achieve a maximum of 2°C of global warming by 2100, unless significant changes in greenhouse gas emissions can be achieved, climate models are predicting global warming of 4°C or more by 2100[34].

What would 4°C of global warming look like? CSIRO has sought to demonstrate the effect of predicted changes by showing what regions would be like in 2100. For example, a 4°C rise in average temperature would make the climate of ***Sydney*** like the current climate of ***Brisbane***[35].

Localities in eastern Australia would generally adopt the current climates of regions well to the north (e.g. Sydney -> Brisbane) and coastal regions would tend to adopt climates more like those of the drier interior. In wheat belt towns, such as Dubbo, the climate would become like the arid interior.

The results are striking:

- Melbourne becomes like West Wyalong and Gawler
- Sydney becomes like Brisbane and Hervey Bay
- Dubbo becomes like Charleville and Emerald
- Brisbane becomes like Ayr and Mareeba
- Cairns becomes like Weipa

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[33] https://www.climatechangeinaustralia.gov.au/en/climate-projections/explore-data/threshold-calculator/. Acc. 9-4-2020

[34] Climate Change in Australia CSIRO & BoM (2007)

[35] Australian climate at four degrees or more of global warming Penny Whetton (CSIRO) and David Karoly (Uni Melb.)

7.6 Extreme weather events

Discussions about a 2°C rise in average temperature as a result of increasing concentrations of greenhouse gasses in the atmosphere tend to understate the likely impacts we will see as a result of this change. These likely impacts are increased intensity and frequency of extreme weather events such as floods, cyclones, droughts and heatwaves. These events, together with the predicted rise in sea levels, will have a far more significant impact on agriculture and the supply of inputs to mushroom producers than a 2°C increase in average temperature alone.

While it can be difficult to attribute individual extreme events to a changing global climate, examining extreme incidents collectively on a global scale and comparing them to historical averages, significantly increases the certainty with which judgements can be made. To address this issue, the IPCC has conducted a study on the effect of climate change on the occurrence of extreme weather events, producing a report on the risks of extreme weather events: *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the intergovernmental panel on climate change*[36]. This detailed report (592 pages) has examined the available data and has described likelihoods of a range of extreme events occurring. A summary of the study's findings are outlined below:

Temperature

- It is ***virtually certain*** that daily maximum temperatures will increase and reach extreme levels more often, while extreme cold events will decrease, in all parts of the world this century.
- It is ***very likely*** that the length, frequency, and intensity of warm spells or heatwaves will increase over most land areas.
- A 1-in-20 year hottest day is ***likely*** to become a 1-in-2 year event by the end of the 21st century in most regions, except in the high latitudes of the Northern Hemisphere.

Rainfall

- It is ***likely*** that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe. Heavy rainfalls associated with tropical cyclones are *likely* to increase with continued warming.
- There is ***medium confidence*** that, in some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions.
- A 1-in-20 year annual maximum daily precipitation amount is ***likely*** to become a 1-in-5 to 1-in-15 year event by the end of the 21st century.

Cyclones

- Average tropical cyclone maximum wind speed is ***likely*** to increase.
- It is ***likely*** that the global frequency of tropical cyclones will either decrease or remain essentially unchanged.
- There is ***medium confidence*** that there will be a reduction in the number of extratropical cyclones averaged in each hemisphere.

[36] Field, C. B., V. Barros, et al. 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. Special report of the Intergovernmental Panel on Climate Change.

Drought

- There is ***low confidence*** that droughts in Australia will intensify. A lack of observational data, and the inability of models to include all factors that influence droughts, preclude stronger confidence than *medium* in drought projections.

Flooding

- There is ***low confidence*** in projections of changes in river floods because there is not enough data, *limited evidence* and because the causes of regional changes are complex.
- There is ***medium confidence*** (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions.
- There is ***high confidence*** that changes in heavy precipitation will affect landslides in some regions.

Sea level rise

- It is ***very likely*** that mean sea level rise will contribute to upward trends in extreme coastal high-water levels in the future.
- There is ***high confidence*** that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels, all other contributing factors being equal.
- The ***very likely*** contribution of mean sea level rise to increased extreme coastal high-water levels, coupled with the *likely* increase in tropical cyclone maximum wind speed, is a specific issue for tropical small island states.

7.7 Understanding the likelihood of changes to key climate variables in a region

The projections to 2070 of mean monthly maximum and minimum temperatures and rainfall were obtained from global climate models using OzClim[37]. OzClim provides an interface for the climate projections from 27 global climate models produced for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007). The projections explicitly account for the key science and policy/behavioural uncertainties outlined below.

Scientific uncertainties

The science uncertainties are accounted for by using projections for 2035 from three global models that cover the range of climate projections. Specifically, the different models have differing climate sensitivities (i.e. the amount of warming for a doubling of atmospheric CO_2). The three models used were NASA/GISS: GISS-AOM, CSIRO Mk3.5 and CCR: MICRO-M. These models were chosen because they produced monthly means for temperature and rainfall and covered the range of changes in climate, from high to low.

Global climate models produce relatively coarse resolution projections. The “down-scaling” process introduces another source of uncertainty. The regional projections used in this report used the same approach[38] and so do not capture this source of uncertainty. The projections obtained from OzClim have a single value for each grid cell of approximately 25km x 25km.

Policy and behavioural uncertainties

A large source of climate projection uncertainty arises from how the global community might behave in the future and the subsequent impact on global greenhouse emissions. To account for these uncertainties the IPCC developed a series of scenarios or storylines. These Representative Concentration Pathways (RCPs) for CO_2-equivalent emissions are standardised scenarios which can then be used by modellers projecting future climate impacts.

The two most commonly used in climate models are RCP 4.5 and RCP 8.5. The RCP 2.6 – in which emissions start to decline in 2020, falling to zero by 2100 – is no longer regularly used.

RCP 4.5 is an intermediate scenario, whereby emissions peak around 2040 then decline. It is expected that this will lead to a global temperature increase of 2 to 3^{o}C by 2100, with an accompanying sea level rise of approximately 0.5 metres.

In RCP 8.5, emissions continue to rise unchecked throughout the 21st century. This is considered a “worst case” scenario, with a nearly 4^{o}C average temperature increase and se level rise of 0.6m.

[37] Ricketts JH, Page CM. 2007. A Web Based Version of OzClim for Exploring Climate Change Impacts and Risks in the Australian Region CSIRO Marine and Atmospheric Res. , Melbourne, Australia.

[38] Whetton et al. 2005. Australian climate change projections for impact assessment and policy application: A review CSIRO Marine and Atmospheric Research Paper 001, December 2005.

How good have past climate change projections been?

Climate change projection has been around for a few decades, which allows us to look at how projections stack up against actual weather.

What were the projections for WA?

In 1988 climate change projections for Western Australia were presented by the Bureau of Meteorology at the Greenhouse 88 Conference[39].

The 1988 climate change projections described the most likely scenario at 2040 and included:

- Southward shift in winter rainfall systems
- Increased sea surface temperatures and southward occurrence of tropical cyclones
- Decreased winter (June-August) rain of between 10% and 20%
- Increased summer rain for Kimberley and Pilbara (50%)
- Increased summer rain over the Wheatbelt and Goldfields (40%)
- Winter temperature rise by 1.8 – 2.1°C (summer up by 1.2 – 1.5°C)

What has been observed?

At the half-way mark the projections have predicted the direction of change accurately (**Table 12**). Some of the specific projections have underestimated the change, e.g. the decline in winter rainfall has been greater than expected, while some have overestimated the change, e.g. the amount of warming has not been as strong as projected. However, this may be due to the simple linear adjustment of 2040 projections to 2012, as changes to the climate are typically non-linear.

Table 12. Comparison of South Western WA 2040 climate projections, linearly adjusted to 2012, with actual changes from 1988-2012.

	Winter	Summer
Rainfall		
Projected 2040	-10 to 20%	Up to + 40%
Projected – adjusted to 2012	-6% to -9%	+19%
Actual (1988-2012)	-15%	+6%
Temperature		
Projected 2040	+1.8 to 2.1°C	+1.2 to 1.5°C
Projected – adjusted to 2012	+0.3 to +0.4°C	+0.2 to +0.3°C
Actual (1988-2012)	+0.14 °C	+0.03°C mixed pattern

Climate projections for WA, made from as early as 1988, have provided a consistent indication of likely changes to our climate. Weather patterns have changed as expected, but the South West has dried faster than projected. This gives some confidence that the projections for 2070 are realistic.

[39] Ian Foster 2013. Assessment of climate change projections for WA – new tools for adaptation. 2013 Crop Updates Conference, Burswood, 26 February 2013.

8 The impact of mushroom production on climate change

8.1 Greenhouse gas emissions from mushroom production

Spanish study

The diagram below is from studies on the environmental impact of mushroom production by Levia et al. (2017) at the University of la Rioja[40]. It divides the mushroom production process into three main sub processes with appropriate inputs in order to analyse where CO_2 emissions occur:

- Mycelium production (spawn production)
- Compost production
- Cultivation (mushroom growing)

Unfortunately, this model fails to include the significant emissions caused by mining of peat for use in casing. Indeed, Levia et al. (2015)[42] include a ***negative*** CO_2-e value for casing material, seemingly on the (unsupported) assumption that it will absorb CO_2 from the atmosphere during use. Moreover, CO_2 emissions also occur in cooling, packing and transport – which are outside this schematic of the industry.

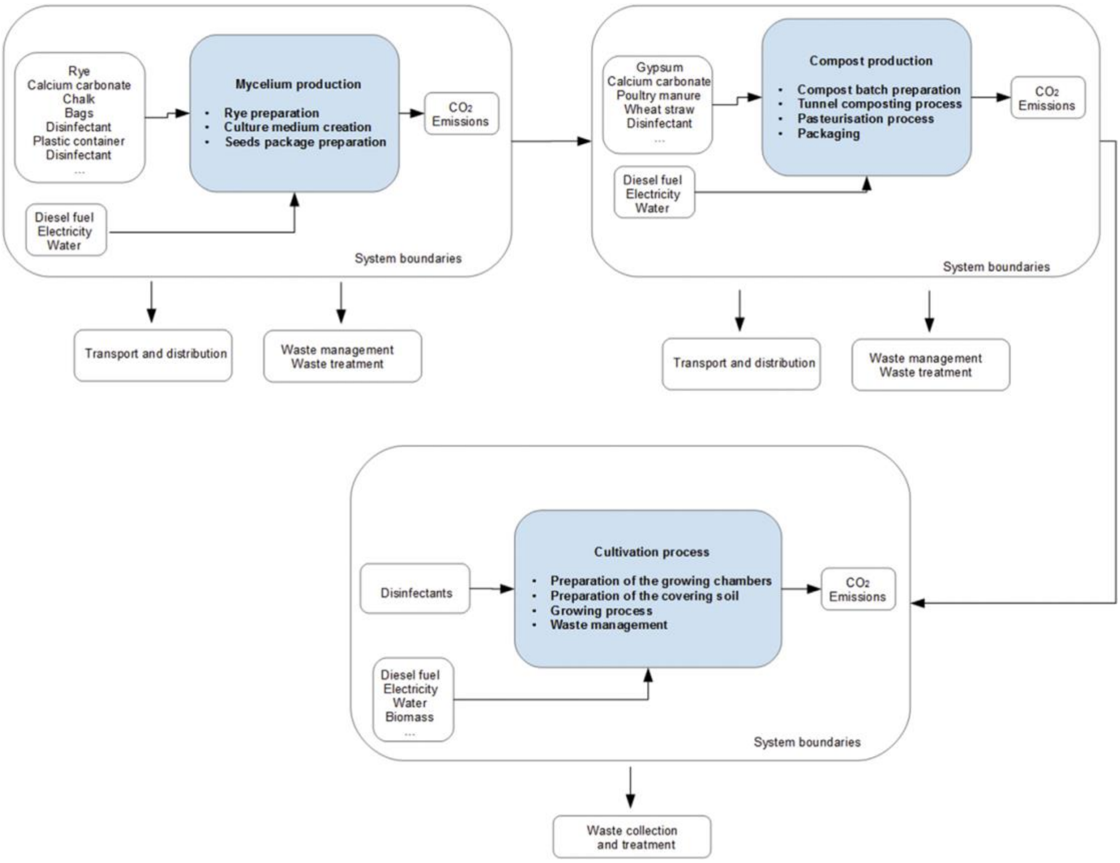

Figure 30. The overall mushroom production process showing inputs from a carbon footprint perspective

[40] Leiva, F.J., García, J., Martínez, E., Jiménez, E. and Blanco, J., 2017. Scenarios for the reduction of environmental impact in Agaricus bisporus production. Journal of Cleaner Production, 143, pp.200-211

In spite of not including peat in their assessment, an earlier life cycle analysis of mushroom production by the same group determined emissions of **4.42 kg CO_2-e per kg** of mushrooms produced[41]. The activity with the greatest impact was temperature management within the growing rooms.

Table 13: Global warming potential of mushroom production from Leiva .

Impact Category	CO_2e per kg
Preparation of the covering soil	-1.37
Preparation of the growing chambers	-1.45
Growing process	7.1
Waste management	0.000392
Ventilation	0.0151
Climate control	0.133
Total	**4.42**

USA study

A study of greenhouse gas emissions (life-cycle analysis) by University of California, Davis estimated that global warming impacts range from **2.13 to 2.95 kg CO_2e per kg** of mushroom product, slightly lower than mushroom studies conducted for Australian and Spanish production systems[42].

Again, energy used to manage temperature inside growing rooms was the main source of greenhouse gas emissions, followed by production of compost substrates, emissions from composting, and transportation.

Transport of peat and materials used to make compost contributed to 60% and 36% of the total transportation impacts respectively. Unlike the Leiva study, emissions from degradation of peat are included (0.3726 kg CO_2/kg peat/year), even if the lost opportunity for sequestration is beyond the scope of the study.

This study also considered the gasses released during composting, which include methane, nitrous oxide and ammonia, to be a major source of emissions. Windrow systems can release 4.06×10^{-4} kg NH_3, 1.83×10^{-3} kg CH_4 and 7.5×10^{-5} kg N_2O per kg compost produced[43]. Tunnel composting systems may release even higher levels of ammonia[44]. However, it should be noted that there is no specific data on greenhouse gasses released from production of Phase 1 and Phase 2 mushroom compost. Modern facilities utilise underfloor ventilation, cooling and damping to maximise efficiency of the composting process. Moreover, the straw and manure used to create compost are organic waste products. It is unclear whether using them to create mushroom compost increases or decreases total emissions from their inevitable degradation.

[41] Robinson, B., Winans, K., Kendall, A., Dlott, J. and Dlott, F., 2019. A life cycle assessment of *Agaricus bisporus* mushroom production in the USA. The International Journal of Life Cycle Assessment, 24(3), pp.456-467.

[42] Leiva, F.J., Saenz-Díez, J.C., Martínez, E., Jiménez, E. and Blanco, J., 2015. Environmental impact of *Agaricus bisporus* cultivation process. European Journal of Agronomy, 71, pp.141-148.

[43] Saer A et al. 2013. Life cycle assessment of a food waste composting system: environmental impact hotspots. J. Clean Prod. 52:234-244.

[44] Cadena E et al. 2009. Environmental impact of two aerobic composting technologies using life cycle assessment. Int. J. Life Cycle Assess. 14:401-410.

The co-product generated by the system, spent mushroom substrate (SMS), was considered to provide a small CO_2-e credit as it can replace other fertilisers / soil amendments.

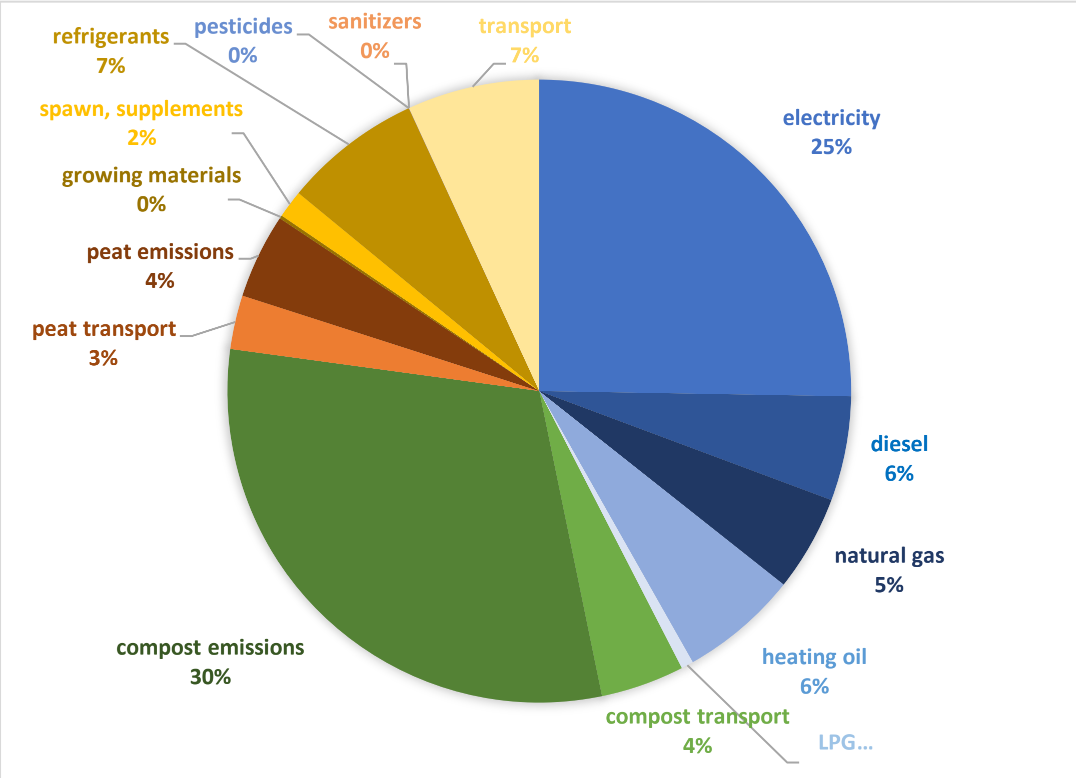

Figure 31. Global warming potential of the mushroom industry, calculated from CO_2e per kg of mushrooms produced, by input or process. Derived from Robinson et al., 2018. "Compost emissions" are based on gasses released during windrow composting of organic materials, and may not accurately reflect global warming potential due to mushroom production, of itself.

West Australian study – Curtin University

A similar life-cycle analysis conducted by Curtin University in Western Australia estimated that the farm emitted **2.75 kg CO_2-e per kg** of mushrooms produced. This compared to 3.4 kg CO_2-e per kg for a strawberry farm and 3.8 kg CO_2-e per kg for a lettuce farm[45].

Most emissions were from compost production as well as transporting peat, compost and compost ingredients (Figure 32) rather than from mushroom production itself. As a result, 52% of emissions occurred pre-farm, 25% at the growing facility, and 23% post-farm, which included transport to retailers.

This study did not include consideration of gasses released during composting, but rather the energy used to transport and process raw materials (70% of total). Similarly, it did not consider methane or CO_2 released due to extraction and degradation of peat, but rather simply the energy required for transport (11% of total). The energy used on the farm itself was a relatively minor contributor.

[45] Gunady, M.G., Biswas, W., Solah, V.A. and James, A.P., 2012. Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactuca sativa), and button mushrooms (Agaricus bisporus) in Western Australia using life cycle assessment (LCA). Journal of Cleaner Production, 28, pp.81-87.

O'Halloran et al (2008), in a study of emissions by the vegetable industry[46], also noted the major impact of transport. Reducing distance where possible, using energy efficient fuels and always loading containers to capacity are suggested as ways to reduce this impact.

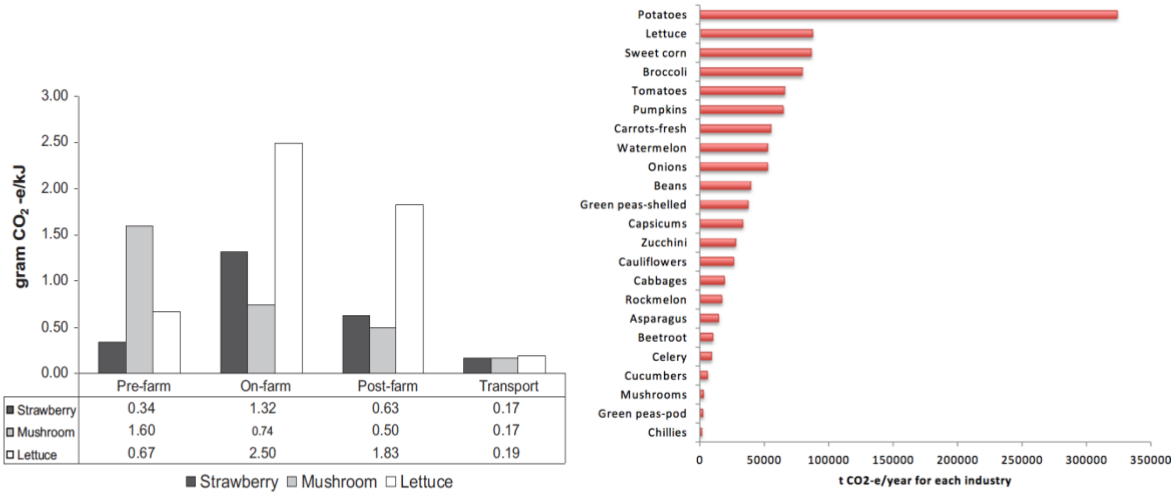

Figure 32. GHG emissions (gram CO_2 equivalent) for 1 kJ strawberry, lettuce, and mushroom production in Australia[45] (left) and total CO_2 equivalent emissions for major horticultural industries in Australia[47] (right)

It is interesting to compare the GHG emissions of the mushroom industry as a whole compared to the vegetable sector. According to a study by Maraseni et al. (2010), mushrooms are a lower contributor to agriculture GHG emissions than most vegetable crops (Figure 32), when calculated for each sector as a whole.

Conclusions

The three life cycle assessments considered here estimate that 2.1 to 4.4kg CO_2-e are released for each kg mushrooms produced. While this seems relatively consistent, the studies vary widely in how they approach measuring the global warming potential of mushroom production.

The limited / non-consideration given to the impact of peat extraction as both a source and sink of CO_2-e may have resulted in underestimation of the impacts of mushroom production. Conversely, including the release of gasses during composting may overestimate the industry's impact, given that these are waste products which will degrade whether utilised or not.

Life cycle assessment for any crop is clearly complex, variable, and difficult. However, the ultimate goal of all such studies is to identify ways in which industries can reduce their environmental impact. For the mushroom industry it seems clear that this means minimising energy used for transport of raw materials, production of compost and managing temperature inside growing rooms and, potentially, replacing use of imported peat.

[46] O'Halloran, N., Fisher, P., Rab, A., 2008. Options for Mitigating Greenhouse Gas Emissions for the Australian Vegetable Industry. Department of Primary Industry, Tatura, Victoria.

[47] Maraseni, T.K. et al., (2010) An assessment of greenhouse gas emissions from the Australian vegetables industry. Journal of Environmental Science and Health Part B 45, 578–588

9 Mushroom pest ands diseases

9.1 Introduction

In a risk analysis report commissioned by the UK mushroom industry (Woodhall *et al* 2009), the authors found 19 species of fungi, 11 bacterial species and five viruses to be directly pathogenic on *Agaricus bisporus* mushroom crops worldwide. In addition, 21 insect pests, 22 mite species, 28 mycophagous nematode species and 18 saprophytic nematode species were found to be associated with cultivated mushrooms, while 59 species of weed moulds were accredited with loss of productivity and quality through direct competition with *Agaricus bisporus*. In comparison, there are five pathogenic fungi, two pathogenic bacterium species, one virus strain and three species of fly known to occur within Australian mushroom crops. There are numerous weed and competitor moulds, nematodes and mites also present that impact product quality.

While Australia's remoteness from the mushroom industries of the northern hemisphere may have somewhat buffered the local industry against serious crop biosecurity incursions in the past, increased international traffic brought about by trade liberalisation (Josling *et al* 2003) and the international movement of people and materials (Barker *et al* 2006) has made the global threat of new and emerging mushroom diseases a significant issue to the local industry.

Despite the historical isolation of Australia, devastating mushroom diseases first experienced by the European and North American industries as minor infections of little significance eventually found their way to Australia. They have severely impacted - and continue to impact - the local industry.

The impact and influences of predicted climate change on artificially cultivated button mushrooms are unknown. So far research into the influence of climate change has primarily focused on staple food crops, commercially valuable plantation timber species and species of environmental significance. There has been no research of note undertaken on this cash crop (David Beyer, Penn State University, Pennsylvania United States; Lise Korsten, University of Pretoria, South Africa; Bill Barber, Giorgio Mushrooms, Pennsylvania, United States: pers comm May 2020). Consequently, without evidence to formulate an accurate picture of how cultivated mushrooms will respond to climate change, most predictions are supposition based on experience in the mushroom industry. However, potential key risk areas have been identified and ranked (Table 2).

9.2 The current disease status of the Australian industry

Established diseases

The currently recognised diseases of mushrooms in Australia are caused by fungal, bacterial and viral pathogens (Table 14). By far the most persistent and devastating are fungal diseases, primarily Dry Bubble (*Lecanicillium fungicola*) and Cobweb (*Cladobotryum mycophilum*). Unlike the bacterial diseases which are essentially controlled by water treatment and careful environmental monitoring, management of fungal diseases requires a coordinated IPM approach and, above all, a dedicated effort by all farm personnel.

Fungal diseases of mushrooms are the most difficult to manage as environmental conditions in the grow room, set to optimise the growth of *Agaricus*, also optimise the growth of invading fungal pathogens. Moreover, treating the fungal infection without harming the fungus host is a delicate balancing act, particularly if fungicides are applied to control the infection. Fungal mushroom pathogens also produce extremely high numbers of resistant spores, each one capable of initiating a new infection if there are favourable conditions for germination. Spores are capable of surviving in grow rooms, throughout the farm and within its surrounds for long periods, ensuring a disease reservoir and an ever-present threat of infection. It has been estimated that a single Dry Bubble mushroom will produce in excess of 30,000,000 *Lecanicillium* spores hr^{-1}, yet only 2,500 spores kg^{-1} of casing is sufficient to cause significant yield reduction, while 25,000,000 spores kg^{-1} casing will result in total crop loss (Beyer 1994). Given that even a moderate Dry Bubble outbreak will result in many symptomatic bubbles developing in a single grow room, the number of spores produced by this pathogen is highly significant.

Table 14. Summary of diseases of cultivated mushrooms in Australia. Table compiled by W. Gill from numerous sources.

	Pathogen	Common name	Status*	Reference
Fungus	*Cladobotryum mycophilum*	Cobweb	Established	Grogan (2006)
	Cladobotryum dendroides	Cobweb	Unknown	McKay *et al* (1999)
	Cladobotryum asterophorum	Cobweb	Emerging	Gill unpublished (2018)
	Lecanicillium fungicola	Dry Bubble	Established	Berendsen *et al* (2010)
	Mycogone perniciosa	Wet Bubble	Emerging	Fletcher *et al* (1995)
	Syzygites megalocarpus	Troll Doll	New	Beyer *et al* (2013)
	Trichoderma spp.	Saprophytic green mould	Established	Fletcher & Gaze (2008)
	Trichoderma aggressivum	Compost green mould	Emerging	Rinker & Alm (2000)
Bacterium	*Burkholderia gladioli* pv. *agaricicola*	Bacterial soft rot	New	Lincoln *et al* (1991)
	Ewingella americana	Internal stipe necrosis	Emerging	Inglis *et al* (1996)
	Janthinobacterium agaricidamnosum	Bacterial soft rot	New	Lincoln *et al* (1999)
	Mycetocola sp.	Bacterial pit	New	Hamidizade *et al* (2020)
	Pseudomonas agarici	Drippy gill	Emerging	Young (1970)
	Pseudomonas fluorescens	Mummy disease	Unknown	Schisler *et al* (1968)
	Pseudomonas 'gingeri'	Ginger blotch	Established	Wong *et al* (1982)
	Pseudomonas 'reactans'	Bacterial blotch	Emerging	Iacobellis & Lo Cantore (2003)
	Pseudomonas tolaasii	Brown blotch	Established	Paine (1919)
Virus	La France	La France	Established	Deakin *et al* 2012
	Mushroom virus X	MVX	New	Eastwood *et al* (2015)

*__Established__ – present in Australia and commonly expresses; **Emerging** – has been recorded or is established in Australia but expresses new symptomology or with greater vigour overseas; **New** – not recorded in Australia but causes losses overseas; **Unknown** – has been recorded in Australia but current occurrence or identity uncertain

New and emerging diseases

An emerging disease, as defined by Anderson *et al* (2004), is one that is caused by a pathogen that satisfies one or more of the following criteria:

1. has increased in incidence, geographical or host range
2. has changed pathogenesis
3. has newly evolved
4. has been newly discovered or newly recognised

In addition to the established diseases, the MU16003 Project Team has identified several pathogens which are 'new and emerging' to the Australian industry (Table 1). 'New' pathogens are those that have not been reported in Australia but are actively expressing overseas and causing significant losses. 'Emerging' pathogens are those that have either recently arrived and have been observed only sporadically and are not widely established or those that are established but are expressing different symptoms or a greater virulence overseas.

If left unchecked, an emerging disease can result in epidemics of disastrous proportions (Avila-Quezada *et al* 2018). The full understanding of plant pathogen emergence requires knowledge of the host-pathogen biology, but it is possible to identify general trends. The most significant drivers of emerging diseases have been identified for crop plants as anthropogenic environmental change (or pathogen pollution), climate change and agricultural change (Anderson *et al* 2004), some aspects of which are pertinent to mushroom cultivation.

Susceptibility of *Agaricus bisporus* to exotic diseases

Button mushroom crops under protected cultivation are highly susceptible to incursion by exotic pathogens for several reasons:

- all current commercially cultivated mushroom strains are derived from the same parent hybrid strain (Imbernon *et al* 1996; Kerrigan 2000); they have approximately 99% of genetic single nucleotide polymorphic markers in common (Sonnenberg *et al* 2011) making them virtually genetically identical. Analysis has shown that most present-day white commercial cultivars are derived in this way from Horst U1 hybrid released in 1981 (Sonnenberg *et al* 2016). This ensures that globally, mushrooms form an intensive monoculture and are equally susceptible to the same pathogens
- as all mushroom crops are more-or-less genetically identical, they are grown under the same environmental conditions worldwide. Newly introduced exotic pathogens do not have to survive an Australian 'off-season' or acclimatise to Australian conditions as a pathogen of a broadacre crop would; the Australian mushroom growing environment is identical to that in the country of origin of the pathogen
- mushrooms do not have a protective outer layer such as a protective waxy cuticle found on fruit, stems and leaves of plants or a layer of sloughing tissue such as the bark on tree trunks
- the mushroom grow room environment is created to optimise mushroom growth. These conditions are also optimal or near optimal for growth of mesophilic organisms which include all known fungal and bacterial pathogens
- effective management of a novel fungus disease of another fungus (the mushroom) with potentially fewer chemical products available is challenging
- standard, everyday mushroom cultivation practices such as harvesting, watering and spot treatment (when performed incorrectly, which is more often than not), disperse spores and infective propagules of pathogenic fungi

- the cultivation of *Agaricus* is a continuous process in which crops of different ages are grown adjacent to each other, a situation ideal for spreading and perpetuating pests and diseases (Gandy 1981)
- the mushroom growing environment is an enclosed system – spores and propagules can accumulate and survive throughout the facility, creating significant but undetected disease reservoirs
- mushroom grow rooms invariably host significant vectors of pathogen spores and infective particles, such as flies and mites

The cost of disease

The impact of disease influences the financial viability of the mushroom farm. Growers say anecdotally that the first and second flush yields pay for the costs of growing mushrooms while the third flush yield accounts for the profit. Being older, it is the third flush which is most often affected by disease. Costs associated with disease management are manifold and extend beyond the calculable market dollar value. They can be broken down into direct and indirect costs (Sinden 1972; Arrold 1981; Gandy 1981).

Direct costs include:

- reduction in yield
- reduction in quality leading to downgrading and disposal of product
- loss of market share while being unable to satisfy demand and fill orders
- chemical purchases – pesticides, salt and sanitisers – to control the disease and its vectors
- labour and machinery to apply them
- labour to inspect crops, spot-treat and manage infections. One grower recently reported investing an extra 70 man-hours/week to manage a Dry Bubble infection

The indirect costs include:

- filtration of air
- unscheduled and early/more frequent cookouts (and treatment of trays where applicable)
- adjusting cropping cycle and environmental parameters to provide less favourable conditions for the pathogen, but causing a reduction in quality and yield of product
- adjusting cropping cycle and prolonging the harvest or shifting peak harvest to weekends or weekdays when product is in less demand
- growing a disease ‘cycle-breaking’ strain which is less susceptible to the pathogen, but which may be of lesser quality and less desirable in the market

In times of high disease pressure, staff morale drops and a laissez-faire attitude may prevail resulting in lack of attention and poor decisions. It can lead to expensive mistakes (comment made to the MU16003 Project Team by a NSW grower in 2016). Furthermore, as yield and quality reduce, harvesting hours are often slashed. Trained harvesting staff leave to find other work and their replacements need to go through extensive training once the outbreak is resolved. The farm must then work through the period during which the new staff have yet to attain peak performance.

Grower-reported shortages of mushrooms in the marketplace can be caused by disease pressure on-farm and are indicative of how significantly pests and diseases influence the industry, and impact on the bottom line. Despite many years’ experience by growers managing established and well-known mushroom pathogens, mushroom diseases still cause significant losses.

The arrival of an exotic, unknown pathogen may prove devastating to the Australian mushroom industry if it is unprepared. In the case of Troll doll disease (*S. megalocarpus*), one author stated that the new pathogen had probably been expressing in crops long before it was formally reported, primarily because the new symptomology had been overlooked or mis-diagnosed as cobweb or merely ignored because "…it does not fit the usual categories" (Miller & Spear 2014), resulting in a build-up of undetected inoculum on exposed farms.

The impact of an emerging disease on a monoculture can be catastrophic. There are two infamous historical examples illustrating the devastating effects that an emerging disease can have when infecting a staple crop. The introduction of a new strain of *Phytopthora infestans* potato blight to Ireland in the 1840s resulted in the 'Irish potato famine' which led to mass emigration and the death by starvation and famine-related illnesses of more than 1 million people (Strange & Scott 2005; Giraud *et al* 2010). Similarly, the Great Bengal Famine of 1943 led to the death by starvation of more than 2 million people after the rice crop was decimated by the emerging fungus *Cochiobolus miyabeanus* (Strange & Scott 2005).

In contrast, infections of cash crop monocultures can have less severe ramifications. The introduction of the emerging pathogen *Cochiobolus heterostrophus* to the US in 1970-71 caused southern corn leaf blight and devastated the industry, but no deaths were directly attributed to this outbreak (Strange & Scott 2005). Similarly, the impact of an emerging mushroom disease can be devastating for individual farms and the industry as a whole but will not cause mass deaths and social upheaval. For example, the 1998 outbreak of Mushroom Virus X disease in the UK impacted 80% of commercial growers, who accrued losses of about £50,000,000, resulting in farm closures and the loss of up to 800 jobs (National Audit Office 2003).

9.3 Impact of climate change on pests and diseases

Expression of established diseases

Any changes in ambient climate will be mitigated by close control of the grow room environmental parameters as per 2.1 above. Consequently, expression of the established diseases will remain as they are. However, in the event of equipment failure, the impact may be more severe as rooms may overheat more quickly with increased external temperatures, and more intense and frequent heatwaves.

Dispersal of established diseases

Insects will respond to the influence of rising temperatures from climate change. Their metabolism increases and population numbers escalate (Sharma 2014) likely through higher reproductive and developmental rates. Evidence for this already exists in New South wales where the Phorid numbers on farms have persisted throughout winter for the past two years or so, instead of falling off during the traditionally cooler winter season.

This is also occurring in Pennsylvania where flies have been active year round for the past decade, since winter frosts all but disappeared (Bill Barber, Giorgio Mushrooms, Pennsylvania, United States: pers comm May 2020). In Pennsylvania fly populations have become so active and large that they have 'invaded' homes around Kennett Square, becoming extremely problematic for residents of this mushroom growing centre.

Mushroom flies require moisture to flourish. The climate model predicts higher temperatures, more intense and more frequent heatwaves, and less rainfall. As climate evolves, it is possible that increasing drought conditions will somewhat counter increased fly activity from rising temperatures. Sciarids frequent leaf litter, rotting vegetation and damp areas around the farm. These habitats are less likely to persist deeper into the climate change cycle.

In the short term, it is likely that fly numbers will continue to increase resulting in a high dispersal rate of vectored diseases like Dry Bubble. However, as heatwave conditions establish, it is possible that flies will become prevalent only in winter, and be scarce during hotter drier summers.

For diseases that rely on wind dispersal such as Cobweb, the hotter drier conditions will create more dust around the grow rooms and farm environment. The dust, incorporating Cladobotryum spores will be aerosolised and dispersed by winds.

Invertebrate pests

Mites are introduced into the mushroom growing system on compost raw materials, primarily wheat straw, but also cotton hulls and poultry manure (Clift 1979). Mycophagous mites are rare - most mites occurring in mushroom crops are saprophytic or predatory feeders. They are not considered primary pests in themselves, but they do contribute significantly to the spread of weed moulds and pathogens such as *Trichoderma* and *Lecanicillium* (Clift & Terras 1994).

Nematodes are also introduced on the compost raw materials and reproduce rapidly. High numbers foul the mushroom beds with their waste products. The compost becomes wet, heavy and inconducive to *Agaricus* mycelium growth, resulting in significant yield reductions.

During Phase I when compost temperatures may exceed 80°C at the centre of the stack, invertebrates survive by migrating to the outer margins. Efficient pasteurisation during Phase II, when compost is uniformly held for a minimum of 3 hours at 60°C (Fermor *et al* 1985; Fletcher *et al* 1989), will kill invertebrates.

It is only when compost is mixed unevenly, heated unevenly and/or mites and nematodes are able to shelter in cracks and cooler niches that they can survive Phase II composting. Those that do persist into the cropping system can be controlled by application of registered acaricides and increased hygiene awareness.

The influence of climate change on the numbers and activity of these invertebrates is unknown. Because insect metabolism, reproduction and development is generally expected to increase (Sharma 2014), we can confidently predict an increase in mite activity and mite populations. However, the impact of increased mite populations on mushroom cropping is mitigated by Phase II pasteurisation. Farms and compost manufacturers will need to ensure their Phase II pasteurisation is as efficient and effective as possible to keep mite populations to manageable levels on-farm should they increase in response to climate change.

Both mites and nematodes are phoretic on Sciarids and Phorids. If populations of invertebrates survive Phase II pasteurisation, they will disperse around the farm and farm environs faster due to increased fly activity and population numbers.

Weed moulds

Although spawn-run compost should be a relatively pure culture of *Agaricus*, a significant number of moulds are able to be isolated from this substrate (Grogan *et al* 2000). Some of these moulds pose no risk to crop yield and quality, while some may compete with *Agaricus* mycelium for nutrients in the compost and reduce yields. Their appearance indicates that the compost is non-selective and susceptible to colonisation by seriously detrimental moulds such as *T. aggressivum* f. *aggressivum* (compost green mould), *Penicillium hermansii* (smoky mould) and *Pythium oligandrum* (black compost) (Noble *et al* 2009) in addition to a number of others (Fletcher & Gaze 2008).

Weed moulds are introduced to the compost on raw materials such as wheat straw and poultry manure or they may be airborne 'blow ins' from the farm or farm environment. Most weed moulds are prolifically sporulating anamorphs of Ascomycete genera which produce copious numbers of tiny spores. With increasing dry periods, dust and airborne spores will be highly mobile, increasing the expected spore loads on farms. Research into the changing profile of the weed mould flora of mushroom farms has begun in South Africa (Lise Korsten, University of Pretoria: pers comm May 2020)

The impact of weed moulds can be mitigated by efficient composting producing a highly selective compost, by maintaining a high level of on-farm hygiene incorporating strict sanitation protocols, and ensuring exclusions and filters are well-maintained and operating efficiently.

9.4 Climate change and new and emerging pathogens

Introduction of new mushroom diseases to Australia

Climate change is likely to have a limited role in the introduction of new diseases to Australia. Pathogens currently occurring in cultivation have arisen from the intensive mushroom growing areas of North America and Europe. Chronology of their appearance would suggest they have generally been introduced into Australia via Europe, probably arising from environmental change with the importation of cultivation materials sourced from mushroom growing areas.

Environmental change refers specifically to the anthropogenic movement of pathogens outside their natural geographic or host species range. The introduction and subsequent establishment of alien pathogens by human activity occurs through international trade in germplasm and live plants, and modifications to farming techniques (Anderson *et al* 2004). Changes in cultivation technique have influenced the expression of modern mushroom disease. Most *Agaricus* pathogens having emerged since cultivation began moving 'indoors' soon after World War II, when the intensive protected cropping system we now know was created.

A more recent example of the influence of cultivation technique on pathogen emergence is the appearance in Spain for the first time in 2008 of the internal stipe necrosis pathogen *Ewingella americana* leading to significant production shortfalls. This coincided with the widespread adoption in Spain of heavier, denser 'deep-dug' black peat in the casing (Carrasco *et al* 2016). Not only does this raw input introduce a different microflora to the cultivation system, but the increased water holding capacity of the black peat leads to a wetter growing environment.

In Australia, the adoption of black peat corresponded with the emergence of *E. americana* with a similar impact on crop productivity. More interestingly, the adoption of black peat in Australia also coincided with the emergence of a damaging and highly virulent strain of *C. mycophilum* (Fletcher *et al* 2004) which favours the increased temperature and humidity at which modern cultivation systems operate.

A change in growing conditions to accommodate the virus disease 'cycle-breaking' species of *Agaricus bitorquis* has previously been demonstrated to provide favourable conditions for the new bacterial soft rot pathogen *Burkholderia gladioli* pv. *agaricicola.* It arose in both New Zealand and England almost concurrently (Lincoln *et al* 1991; Gill & Cole 1992). *Agaricus bitorquis* requires a higher growing temperature than *A. bisporus* so it is sometimes grown as a rotation when a farm is experiencing a virus outbreak.

The virus does not survive the increased growing temperatures, so its reproduction cycle is broken. Bacterial soft rot has expressed only sporadically since and has not been detected outside mushroom cultivation systems. Although a supposition, it is likely that the bacterium exists as an endemic component of the mushroom bed, stimulated by the coincidental cultivation of *A. bitorquis,* which requires higher temperatures. It is difficult to perceive what role climate change could play in introducing new diseases such as those described above when the process of environmental change is so dominant.

As Asia, and more specifically China, now hold a significant stake in global *Agaricus* production, it is likely that novel mushroom pathogens will emerge from this part of the world. *Mycetocola* has just this year been identified as the causal pathogen of *A. bisporus* in Iran (Hamidizade *et al* 2020). It is usually an environmental microbe, and this is the first report of this genus expressing symptoms on mushrooms. There is minor trade of mushroom growing equipment between China and Australia –

inanimate materials such as grow rooms and items of plant. Whether this would be enough to introduce the new pathogen to Australian mushroom farms is unknown, but it is likely that *Mycetocola* will be the first of many new diseases to emerge from Asian *Agaricus* facilities.

Establishment of emerging mushroom diseases in Australia

For emerging pathogens which have been detected in Australia but are not yet established, and for newly introduced pathogens, climate change will be significant. Emerging diseases that rely on insect vectoring will be driven, by predicted increase in fly activity. Likewise, anticipated hotter and drier conditions will be ideal for dust formation and dispersal of emerging diseases that rely on wind assistance.

Trichoderma aggressivum f. *aggressivum* sporulates extremely prolifically. When fresh, the spores are encapsulated in a sticky mucilage to aid dispersal by adhering in clumps to a vector. But when dry, the tiny spores readily become airborne, often incorporated with dust. Predicted extensive droughts and frequent heatwaves will drive dispersal of this pathogen by both flies and wind. Because this pathogen is particularly adapted to bulk Phase III compost handling facilities (Kilpatrick *et al* 2016; O'Brien *et al* 2017), which are becoming more widespread in Australia, compost green mould caused by *T. aggressivum* f. *aggressivum* is a serious disease risk.

Table 15 Risk summary of the influences of climate change on mushroom diseases. Section number refers to body of the text

Description	Risk response due to climate change	Risk rating due to climate change	Comment
Grow room environment	No change	Nil	Climate change mitigated by room environmental controls
Expression of established diseases	No change	Nil	Climate change mitigated by room environmental controls
Dispersal of established diseases	Increase	Moderate	Greater fly activity and increased populations will spread vectored diseases. Dry conditions will facilitate air and dust-borne pathogen dispersal
Invertebrate pests	Increase	Moderate	Increased incidence of mites and nematodes mitigated by effective Phase II pasteurisation and increased hygiene awareness
Weed moulds	Increase	Moderate	Impact of weed moulds mitigated by effective Phase II pasteurisation and conditioning creating a high-quality selective compost. Airborne weed moulds controlled by stringent farm hygiene, the timely removal of spent compost from the farm and strict hygiene protocols enforced
Cool chain	Increase	Moderate	Mushrooms and Phase III compost in the back of a truck will be subject to heatwave conditions for extended periods of time, reducing quality. Significant for farms remote from retail outlets and compost suppliers. On-farm post-harvest packing and cooling may be affected
Introduction of new diseases	No change	Nil	Anthropogenic movement has accounted for the introduction of mushroom diseases in Australia. The mechanism by which a new disease arrives in Australia due to climate change is difficult to envisage
Establishment of emerging diseases	Increase	High	The establishment of a vectored emerging disease will be facilitated by increased insect activity. The establishment of an airborne emerging disease will be facilitated by increased temperatures and more intense and frequent heatwaves and increasingly dusty conditions. *T. aggressivum* f. *aggressivum* is particularly adapted to bulk Phase III handling systems and currently poses the greatest risk to the Australian mushroom industry
Wheat straw supply	Increase	High	Wheat straw of acceptable quality unavailable due to short supply, prohibitive transport costs and competition with biofuel and stock feed industries. Lower quality straw reduces compost quality/selectivity resulting in reduced yields
Wheat straw supply	Increase	Moderate	More pesticides applied to control pests of wheat; increasing residues in compost and possible uptake by mushrooms causing potential food safety issues. Increased fungicide residues on straw may inhibit growth of *Agaricus* resulting in poor colonization and reduced yields. Increased fungicide residues on straw may inhibit thermophilic fungi resulting in non-selective compost and disease and weed mould issues. Non-selective composts open to colonization particularly by *T. aggressivum* f. *aggressivum* especially in Phase III
Wheat straw supply	Increase	Low	Increase in number and variety of weed moulds introduced on wheat straw. More invertebrate pests carried on wheat straw. These risks mitigated by efficient Phase II pasteurisation to eradicate pests and conditioning to create a highly selective compost
Poultry manure supply	Increase	Low	Impact of weed moulds mitigated by effective Phase II pasteurisation and conditioning creating a high-quality selective compost.

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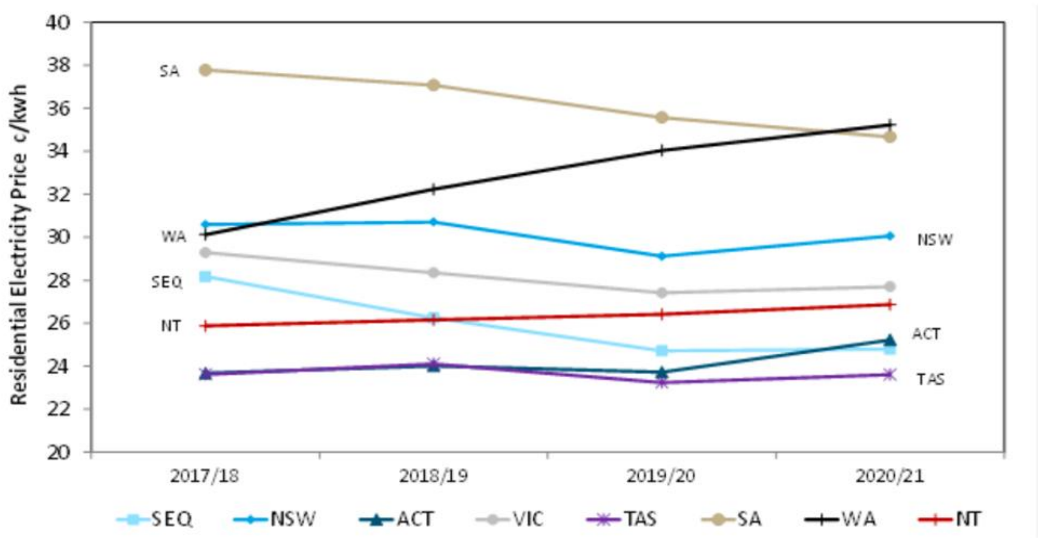
10 Impacts of climate change on energy

10.1 Current energy prices and costs

Electricity usage rates can vary from state to state, and even within different parts of the same state, and from year to year.

The Australian Energy Market Commission publishes an annual Residential Electricity Price Trends report, which can be a useful guide to prices. The report identifies changes in the energy supply chain cost components that are driving residential electricity prices and bills for each Australian state and territory, and nationally, from 2017-18 to 2020-21. Prices are shown in dollars per MWh and exclude daily supply and peak supply charges.

The national average retail price of electricity for 2018/19 was $29.85 c/kWh ($298.50/MWh)[48]. However, prices vary significantly between states (Figure 33). Moreover, businesses are normally able to negotiate greater discounts by purchasing electricity wholesale, so these prices are indicative only.



Source: AEMC

Note: The weighted average of retailer's lowest market offers for the representative consumer was used in South East Queensland, New South Wales, Victoria and South Australia. The weighted average of retailer's lowest standing offers for the representative consumer was used in the ACT and Tasmania. The regulated price set by the state or territory government was used for Western Australia and the Northern Territory. Also note that Victorian prices are set on a calendar year basis.

Figure 33. Australian Energy Market Commission annual Residential Electricity Price Trends report[48]

Interestingly, Australian Government ACCC retail price enquiry (2017) published an internal price comparison of retail electricity charges, and Australia's electricity prices are relatively high compared to most European countries, except for Germany and Denmark[49].

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[48] Australian Energy Market Commission publishes an annual Residential Electricity Price Trends report https://www.aemc.gov.au/sites/default/files/2018-12/2018%20Price%20Trends%20-%20Final%20Report%20-%20CLEAN.PDF accessed 14/2/2020

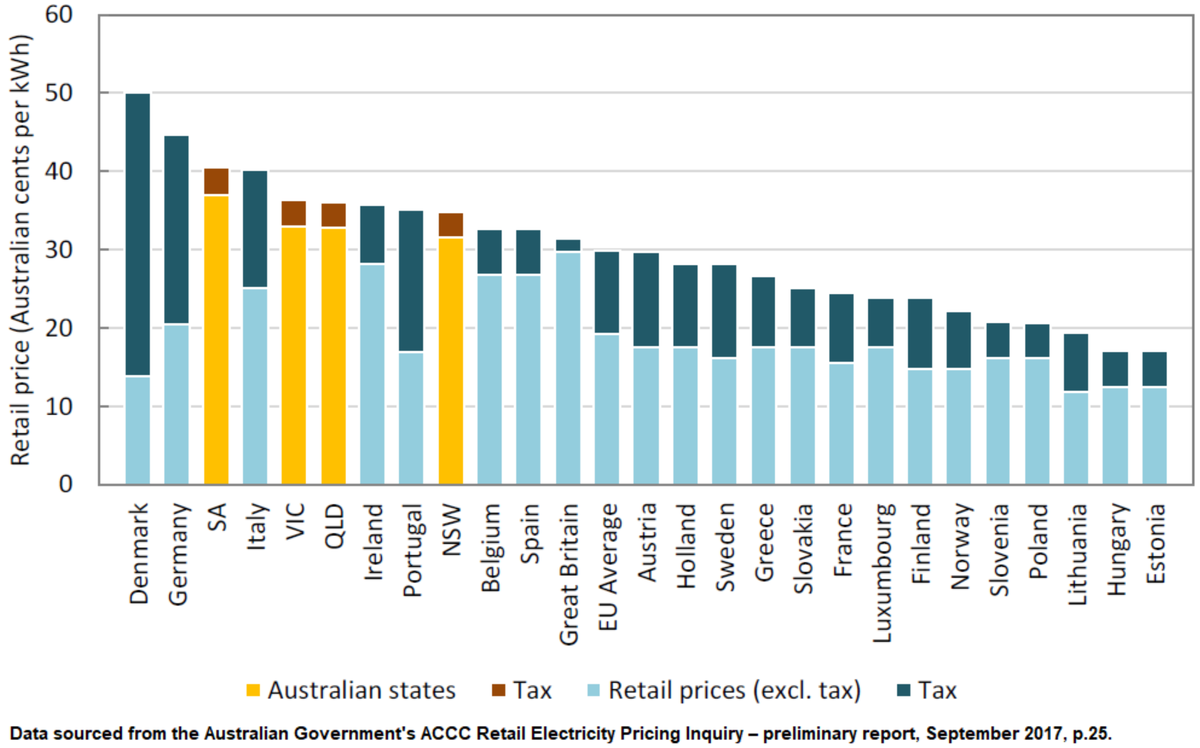

Figure 34. Advertised residential electricity prices, South Australia, Victoria, Queensland, and New South Wales all rated poorly when compared to European countries. Source: ACCC Retail electricity pricing inquiry, 2017.[49]

Typical Australian fuel prices, electricity prices and natural gas prices (May 2020) are shown below in Table 16 to Table 18. The data is taken from the Global Petrol price website[50].

Table 16. Prices per litre of octane-95 gasoline, regular diesel, and other fuels.

Fuels, price per litre	Date	AUD	USD
Gasoline prices	18.05.2020	1.113	0.726
Diesel prices	18.05.2020	1.196	0.781
LPG prices	18.05.2020	0.884	0.577

Note: These are retail (pump) level prices, including all taxes and fees.

Table 17. Average electricity rates per kWh for home and business

Electricity prices per kWh	Date	AUD	USD
Households	01.09.2019	0.332	0.217
Business	01.09.2019	0.253	0.165

Note: In the calculations, the average annual household electricity consumption is used, and for business 1,000,000 kWh annual consumption is used.

[49] https://electricitywizard.com.au/electricity/electricity-cost/how-much-does-electricity-cost/ accessed 14/2/2020

[50] Global Petrol price website https://www.globalpetrolprices.com/Australia/

Table 18. Average prices of natural gas

Natural gas prices per kWh	Date	AUD	USD
Households	01.09.2019	0.115	0.075 USD

Note: For households prices are based on consumption of 30,000 kWh per year, and for businesses, the consumption level used in the calculation is 1,000,000 kWh per year.

10.2 Energy use on mushroom farms

Electricity for cooling, heating and equipment is clearly one of the largest costs of operation for both composting facilities and mushroom farms. Energy costs are generally highest in summer due to cooling requirements. Key energy uses on farm include:

- Cooling/heating of grow rooms
- Heat and steam generation during room cookout
- Cooling/heating of processing and packing areas
- Postharvest cooling and storage of mushrooms
- Equipment such as forklifts, pumps, fans, belts etc.

Some of these may be powered by energy sources other than electricity. The life cycle assessment of mushroom production conducted by Robinson et al[69] in the US suggests that approximately half of the farms' energy use is electricity, with the remainder mainly supplied by heating oil, natural gas and diesel (Figure 35). Electricity is generally the main energy source used by most Australian farms.

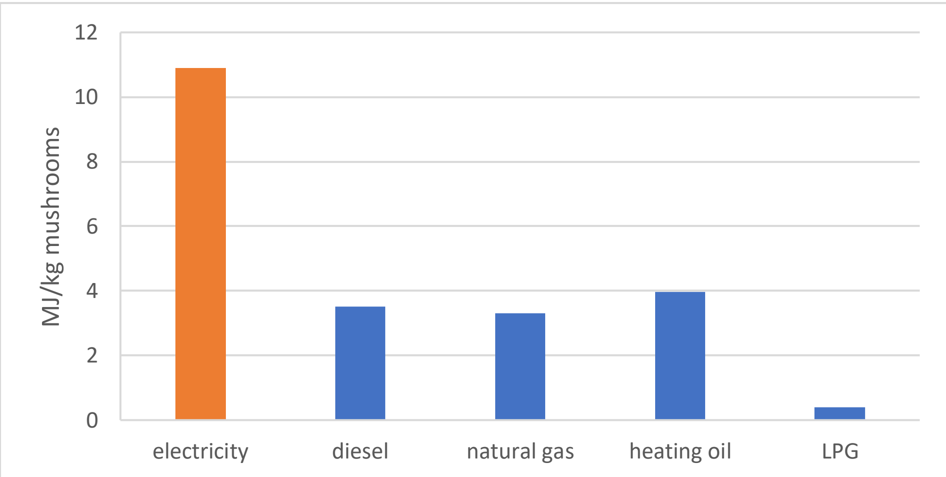

Figure 35. Energy use by US mushroom farms (MJ/kg mushrooms). Derived from Robinson et al., 2019.

10.3 Climate change effects on energy costs

In 2017, the federal government commissioned an enquiry into the future security of the National Energy Market[51]. This was to consider the effects of varying government policy on the price and reliability of energy supplies for domestic and business uses.

There is a great deal of uncertainty about future policy in this area, which can change with an election or even simply party leadership, and may be heavily influenced by targets to reduce emissions. Some of the scenarios considered were:

- Business as usual (BAU), with continued uncertainty over abatement policy and investment decisions
- A clean energy target (CET), where emissions targets must be met
- An emissions intensity scheme (EIS), where rewards and penalties are awarded to power generators based on emissions compared to an industry baseline
- A limited lifetime (LL) approach, where thermal power stations must close after 50 years operation

Perhaps surprisingly, energy costs are highest under the BAU scenario, primarily due to ongoing uncertainty about investment. It is expected that wholesale energy prices will rise gradually from 2020 onwards, plateauing at close to $90/MWh.

Wholesale prices are lowest under a CET scheme, followed by an EIS. This is because the incentives provided to low emission energy producers entering the market puts downward pressure on prices. The EIS applies a direct penalty to existing coal-fired generators, and further distinguishes between brown and black coal, whereas the CET simply caps total emissions. However, adding a limited lifetime approach alone or incombination with either of these approaches results in prices similar to BAU.

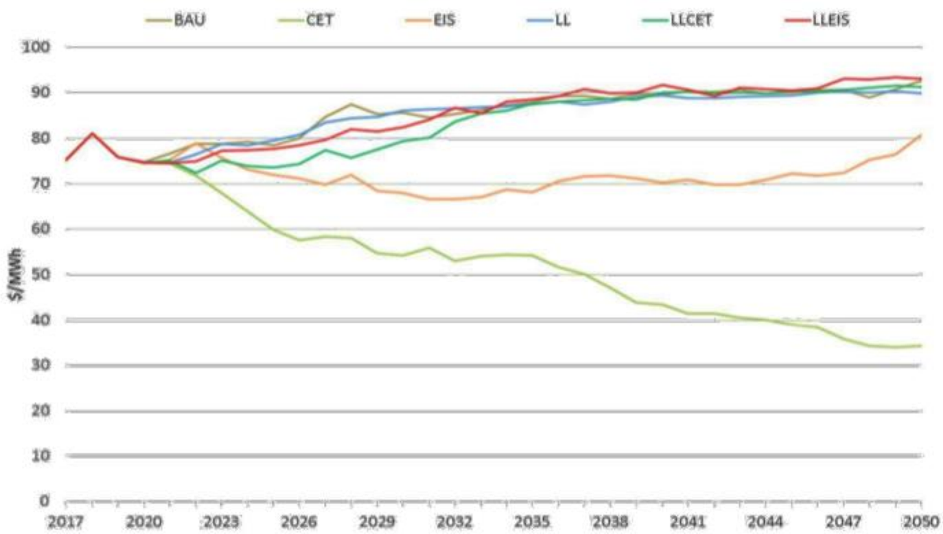

Figure 36. Wholesale electricity prices under different policy scenarios (Business as usual –; Clean energy target –; Emissions Intensity scheme –; Limited lifetime approaches alone – or with CET – or EIS –)

[51] Gerardi W, Galanis P. 2017. Report to the Independent review into the future security of the national energy market. 21 June 2017. https://www.energy.gov.au/. accessed 9-4-2020.

Coal fired generation falls in all scenarios, with or without government policy. Even under BAU, announced retirements, deterioration of performance and ageing will see most coal fired generators cease operation by 2040. This will be replaced with gas-fired power, wind and solar generation and solar with battery storage (Figure 37).

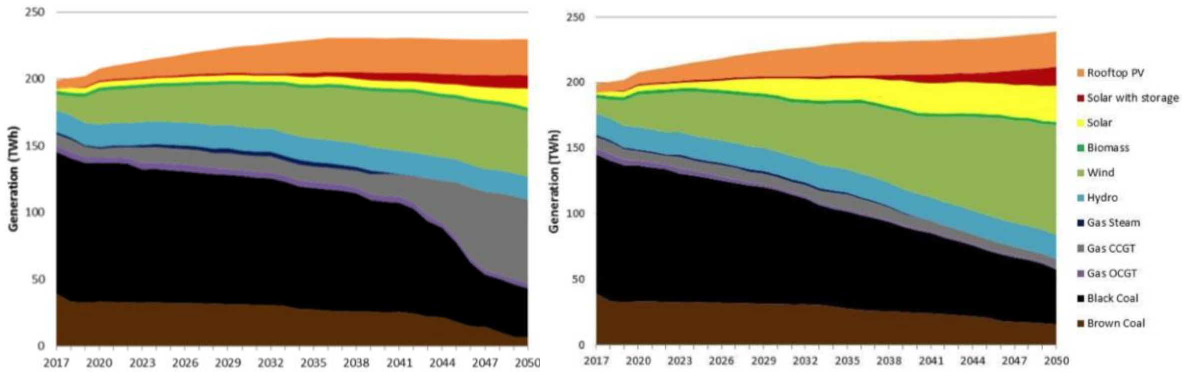

Figure 37.Projected changes in generation type under a business as usual scenario (left) or a clean energy target (right)

The report considers it likely that a price will be placed on carbon at some point in the future – as this was policy at the time of commissioning. It was thought this would commence at $25/t CO_2 and gradually rise to $50/t by 2030. It is estimated that a 1% increase in electricity price will drive a 0.2% to 0.4% reduction in demand. Modelling therefore suggests that the carbon price will have minimal impact on demand, particularly during the summer peak where energy is used for air-conditioning.

However, a carbon price would drive major changes in electricity generation technologies. Black coal and, particularly, brown coal are far more expensive sources of electricity under this scenario than solar or wind generation (Figure 38)[52].

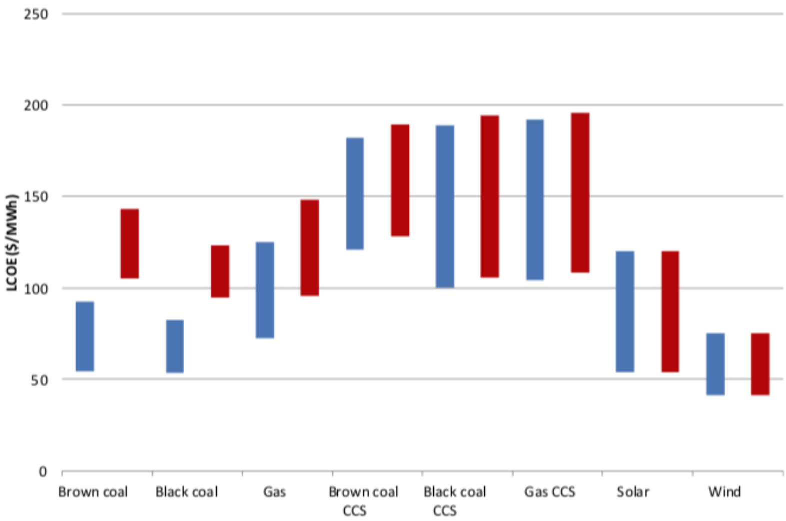

Figure 38. Projected 2030 cost of electricity from different sources with (red) and without (blue) a carbon price. Coal is presented without and with carbon capture and sequestration (CCS) technology. Source: Australian electricity market analysis report.

[52] Brinsmead TS, Hayward J, Graham P. 2014. Australian electricity market analysis report to 2020 and 2030. CSIRO report to the Int. Geothermal Expert group. www.arena.gov.au

What these reports suggest is that under current government policy electricity prices will continue to increase. However, if a clean energy target is mandated, with or without a carbon price, then wholesale energy costs may fall considerably.

11 Impacts of climate change on production inputs

Extreme weather events and droughts can impact on the availability and quality of compost inputs such as straw and poultry manure, as well as on inputs specific to mushrooms production.

11.1 Straw

Wheat straw is the preferred carbon source for making mushroom compost, however, its supply is becoming uncertain. The recent drought reduced availability of hay, while the demand for hay as stock feed increased greatly. Drought increases the competition from the livestock industry straw, leading to higher prices and uncertain supply. Predicted hotter and drier conditions associated with climate change are likely to impact on the availability and quality of dry-land wheaten straw. Irrigated wheat crops could also be impacted by reduced water allocations due to drier conditions. These factors are all negatives in relation to wheat straw for composting[53].

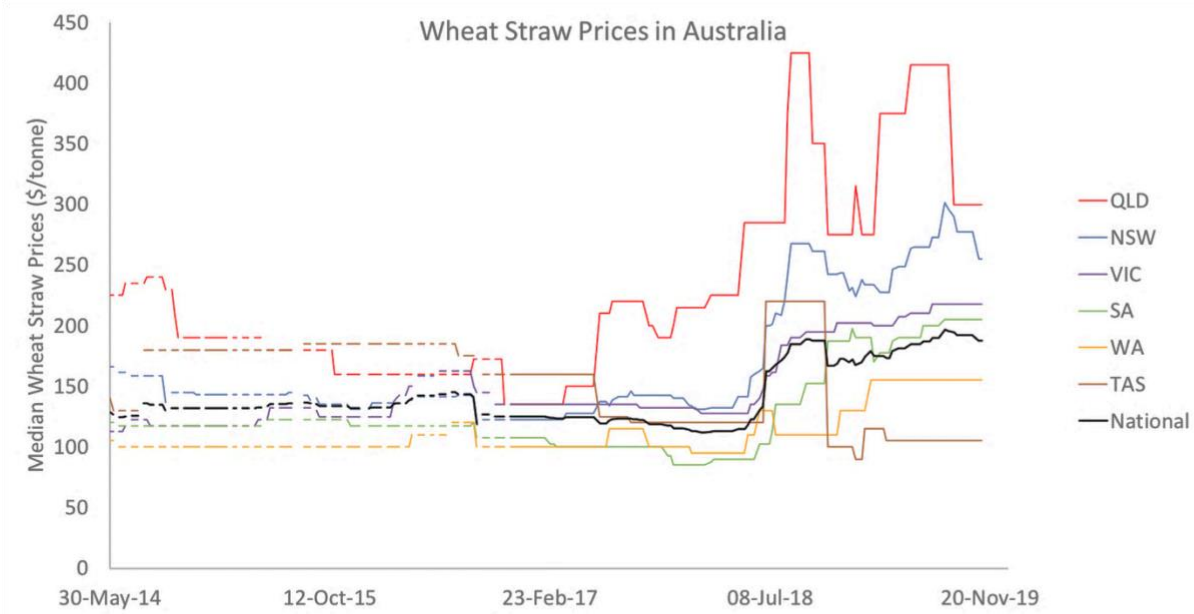

Figure 39. Weekly wheat straw prices in Australia May 2014 to November 2019. Source: Australian Fodder Industry Association, 2020.

Drought through 2017 to 2019 significantly reduced grain crops as well as increased demand for straw as animal feed. The result was volatile and inflated prices for wheat straw in Australia. Price shocks were most extreme and prolonged in the strongly drought affected states of Queensland and New South Wales, shown in Australian Fodder Industry Association weekly price data (Figure 39). Western Australia and Tasmania are less influenced by wheat straw markets compared to the Eastern States of mainland Australia.

The availability, and therefore price, of wheat straw is not only due to crop failures, but also to changed agronomic practices. There is increasing adoption of conservation farming methods as grain growers adapt to a hotter, drier climate. Conservation farming aims to increase or maintain carbon levels in the soil, improve water infiltration, reduce evaporation, insulate the soil from heat and

[53] Jones N. 2013. Raw materials review: wheat straw. The Spawn Run December 2013 pp7-8.

reduce erosion during wind/rain events. As a result, grain crops are frequently cut higher than previously to maximise retention of stubble in the field.

Cutting high (e.g. 60cm instead of 20cm) increases the efficiency of harvesting as the machine can travel faster and fuel/ha is reduced[54]. Leaving stubble in the field and longer also retains nutrients in the system; it is estimated that baling 2t/ha of stubble also removes 10-20kg Nitrogen, 5-15kg potassium, 1 kg phosphorus, 3kg sulfur and various trace elements (Figure 40).

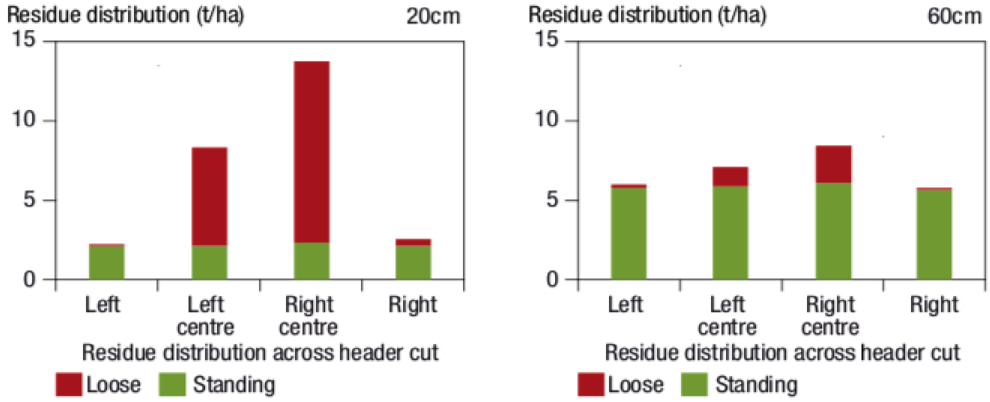

Figure 40. Loose crop residues available for baling when harvesting with 20cm vs 60cm cutting heights. Source: WANTFA

These practices reduce the volume of straw available for baling and, therefore, for production of compost.

Alternatives to wheat straw are discussed in section 13.1 on page 83 of this report, however only waste paper, forestry waste, corn stover and sugar bagasse were identified as viable alternatives.

11.2 Peat

Peatlands are the largest natural terrestrial carbon store. Known peatlands are estimated to cover 3-4% of the worlds land area, containing at least 612 giga-tonnes of carbon[55]. Peatlands continue to sequester significant amounts of CO_2. For example, a recent study by Lunt[56] estimated that peat bogs sequester 9-12 tonnes CO_2/ha annually. In total, peatlands sequester up to 0.5 gigatons of CO_2 each year, representing 1-5% of global anthropogenic greenhouse gas emissions[57].

Conversely, **10%** of global emissions from the agriculture, forestry and land use sector are caused by the draining of peatlands. This equates to almost 6% of global anthropogenic CO_2 emissions[58]. This is because allowing oxygen into the previously anaerobic environment of the peatlands leads to rapid decomposition, emitting large amounts of both CO_2 and nitrous oxide (N_2O).

Moreover, drained peatlands are extremely susceptible to fire, especially when combined with increasingly hot, dry conditions. Such fires can smoulder underground for weeks. For example, in 2018 the Saddleworth Moor peatlands outside Manchester ignited into an intense, wide-ranging fire

54

55 Yu, Z et al. 2011. Peatlands and their role in the global carbon cycle. Eos, Trans. Amer. Geophysical Union 92:97.

56 Lunt, PH, Fyfe R, 2019. Role of recent climate change on carbon sequestration in peatland systems.

57 Friedlingstein PRM et al. 2014. Persistent growth of CO2 emissions and implications for reaching global targets. Nature Geosci. 7:709-715.

58 International Union for Conservation of Nature, https://www.iucn.org/resources/issues-briefs/peatlands-and-climate-change

as a result of drainage of the moors combined with an un-seasonally hot summer[59]. Similarly, the 2019-2020 underground peat fire near Port Macquarie took 210 days to extinguish, and then only with the combination of 260mm of rain combined with pumping 65 megalitres of reclaimed water onto the wetlands[60].

According to the International Union for the Conservation of Nature (IUCN), "*the protection and restoration of peatlands is vital in the transition towards a low carbon economy*". They further propose a moratorium on peat exploitation, and for peatlands to be included alongside forests in agreements relating to climate change (e.g. carbon credits/debits), geodiversity and biodiversity.

It is likely that the European Union will introduce regulations that limit or ban the draining and extraction of peat to reduce European greenhouse gas emissions. There is strong pressure to restore previously exploited peatlands, as well as prevent further drainage and mining of these areas, as a strategy to combat climate change. According to Achim Steiner, previously the executive director of the UN Environment Program, protecting and restoring peatland is "low hanging fruit", being one of the most cost-effective options for mitigating climate change[61];

- Ireland has already closed 17 peat bogs and plans to close the remaining 45 bogs within seven years[62].
- The EU "Peat Life Restore" project aims to restore peatlands in Germany, Estonia, Latvia, Lithuania and Poland in order to meet the objective of reducing greenhouse gas emissions by 40% by 2030 compared to 1990 levels.

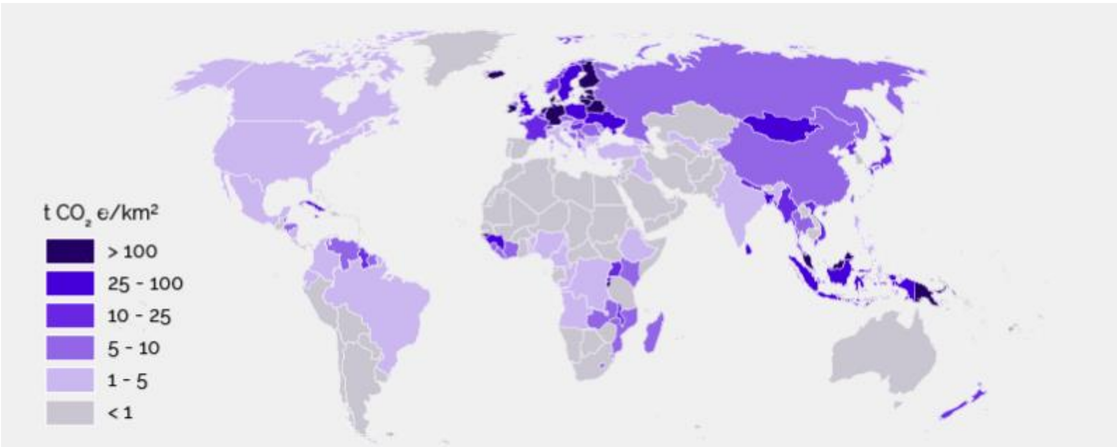

Figure 41. Emissions (tonnes CO_2/km^2/year) from drained peatland. Source: Greifswald Mire Center.

Peat used for casing is therefore likely to become both more difficult to access and more expensive.

11.3 Manures

Chicken manure for compost production may be sourced from broiler sheds or barn-based egg production. The mixture can contain bedding material, feathers, blood, eggs etc. as well as manure. Antibiotics added to chicken feed as growth promoters and therapeutic agents are not fully

[59] Plester, J. 2018. Weatherwatch: Wildfires highlight importance of UK's peatlands. 3 July 2018 www.theguardian.com/news/2018/jul/02

[60] Bungard, M. 2020. Fire near port Macquarie extinguished after 210 days. https://www.smh.com.au/environment/weather

[61] https://www.newscientist.com/article/dn13034-peatland-destruction-is-releasing-vast-amounts-of-co2/

[62] https://www.theguardian.com/world/2018/nov/27/ireland-closes-peat-bogs-climate-change

metabolised within the birds so may also be present in the manure. Other aspects of the birds diet can likewise affect the end qualities of the manure. However, no information on links between chicken diet and manure attributes was found for this review.

Many chicken meat producers previously used rice hulls as bedding material. However, water shortages have seen rice production fall dramatically, reducing availability of this material. While many farms next turned to sawdust and wood shavings, the prices of these materials have also now increased.

A recent study by AgriFutures Australia[63] found that more than 65% of chicken meat producers were looking for alternative sources of bedding materials due to cost and supply issues. For example, wood shavings can cost \$22-\$40/m^3 compared to \$10-\$15/m^3 for straw. The study identified a number of other alternative litter materials including nut husks, oat hulls, stubble pellets, miscanthus grass and tree-litter. The type of bedding material that is used is likely to significantly alter the C:N balance in the waste product. For example, the change from rice hulls to wood shavings reduces N content, with clear implications for the attributes of the resulting compost.

Another change due to increased cost/reduced availability of bedding materials is the more frequent recycling of the litter by re-use, layering or mixing. In the past, about 70% of Australian broiler chickens were grown on new bedding, with the remaining farms practicing partial re-use[64]. In the US, litter may be re-used for up to 2 years before the sheds are fully cleared out. This is made possible by windrowing the bedding inside the shed, allowing it to partially compost, before re-spreading for the next batch of birds[65]. Increasing adoption of this practice has clear implications for the volume and composition of material available for compost production.

Figure 42. Bedding for broiler chickens may be recycled several times before disposal. Source: ABC News 10/5/13

[63] Watson K, Wiedemann SG. 2019. Review of fresh litter supply, management and spent litter utilisation. AgriFutures Australia. 128pp.

[64] Chinavasagam HN, Tran T, Blackall PJ. 2012. Impact of the Australian litter re-use practice on *Salmonella* in the broiler farming environment. Food Res. Int. 45:891-896.

[65] LeBlanc B. et al. 2005. Poultry production best management practices. Louisiana Ag Centre.

11.4 Spawn production and Phase III compost.

Spawn is produced by growing *Agaricus mycelia* over sterilised grains, usually rye, triticale, wheat or millet. While the grain used is a relatively small input to mushroom production, there have been reports of reduced supply and/or poor quality of grain used for this purpose in the recent droughts. Rye in particular is a cool climate grain species largely grown in northern and eastern Europe. Supply of rye is therefore most likely to be affected by rising temperatures.

In the last 10 years there has been a move away from using Phase II compost in cropping rooms to filling trays or beds with compost already inoculated with spawn (Phase III compost). The Phase III material is prepared in bulk. Once the compost is colonized by the *Agaricus* mycelia, the material can be loaded onto trucks for transfer to mushroom farms. This system has the advantage of making more efficient use of mushroom production facilities.

Temperatures during spawn running ideally range from 24 to 27°C[66].If temperatures become very high (>30°C) during transport from compost facility to farm, the mycelia can be damaged (reducing productivity). Susceptibility varies between strains. For example, there is evidence that some hybrid off white strains can tolerate temperatures up to 35°C for 24 hours without loss of yield, whereas a hybrid white strain was negatively affected after only 12 hours at 27°C. Temperatures above 35°C invariably reduce yield, and if these conditions persist for more than 24 hours then yield may be reduced by nearly 60%[67].

The increasing frequency of hot conditions may therefore make it unfeasible to move Phase III compost, or necessitate cooling during transport.

Moreover, hot conditions favour development of green mould, *Trichoderma harzianum*. Managing green mould is particularly challenging for bulk spawn run operations. Although green mould normally spreads only small distances during Phase III composting, the process of loading, transporting and filling compost into growing rooms can easily spread the contamination through an entire batch. The issue may be worsened by high temperatures during transport, as 30°C (or more, perhaps) favours growth of *Trichoderma* while reducing that of *Agaricus*[68].

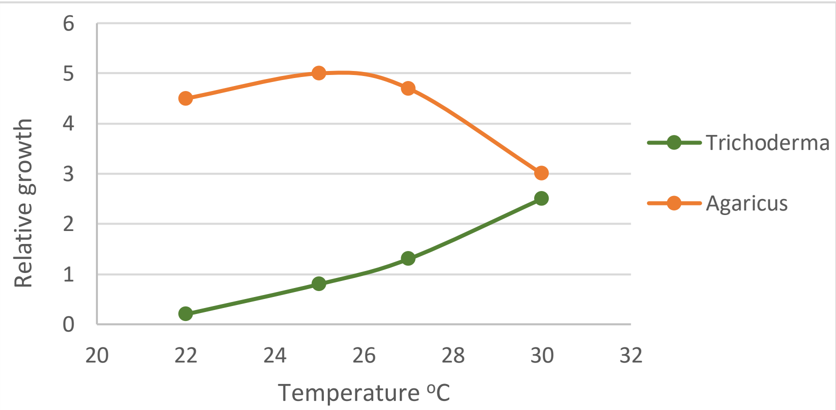

Figure 43. Effect of Phase III temperature on relative growth of *Agaricus* and *Trichoderma* mycelia. From Seaby, 1996.

[66] Noble R. et al. 2008. Measuring and improving the rate of spawn-running in compost. Mushroom Sci XVII, 207-220.

[67] Wuest PJ, Hetrick TR, Wilkinson V. 2004. Agaricus bisporus: temperature management for cultures and spawn run.

[68] Seaby DA. 1996. Investigation of the epidemiology of green mould of mushroom (*Agaricus bisporus*) compost caused by *Trichoderma harzianum*. Plant Path. 45:913-923.

11.5 Water

Mushrooms are more than 90% water. Their production necessarily involves a considerable amount of water, much of which must be reasonably high quality. A US study estimated that 293L of water is required to produce a single kilo of mushrooms! However, this included 229L for electricity and other energy production. If this is deducted, this still suggests that 64L water/kg mushroom is required, of which the major uses are for compost production, spawn and supplements and on-site use[69] (Figure 44). While this estimate of 64L/kg appears high, it may be a considerable underestimation, as does not appear to include water used for washing and sanitising equipment and facilities, or that used by workers.

Access to water is already a key issue faced by some composting facilities and farms. Even where bore water is available, high salt content may limit its use or mean it must first be desalinated. Many Australian farms currently use town water. While this ensures that water is of suitable microbial and chemical quality for all purposes, water restrictions during drought periods can affect farm operations.

One of the key effects of climate change is likely to be reduced availability of fresh water. While water can be recycled on-site, accumulation of salts and other impurities may limit the uses of recycled water.

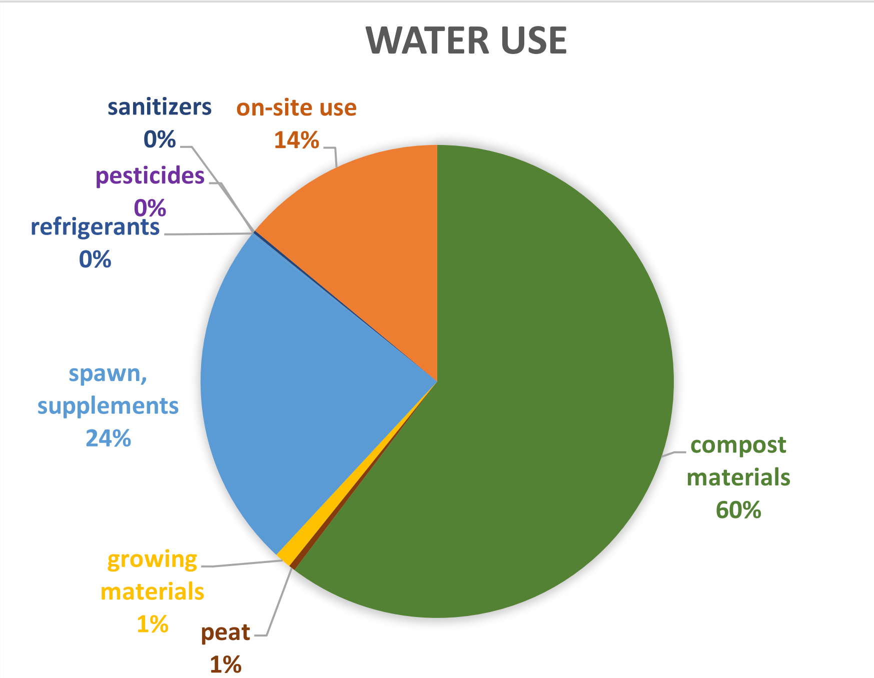

Figure 44. Fresh water use during mushroom production in the US. Derived from Robinson et al., 2018.

[69] Robinson B. et al. 2018. A life cycle assessment of Agaricus bisporus mushroom production in the USA. Int. J. Life Cycle Assess. 24:456-457.

12 Climate adaptation – Energy

12.1 More efficient energy use

Grow rooms

Across all horticulture industries, there is an increasing trend to "Smart Farming" systems, where environmental variables are continuously monitored and, where possible, controlled. Mushroom producers are technologically ahead of most other industries in this respect, as most farms already manage temperature, humidity, atmospheric composition etc.. However, there may still be opportunities to further refine growing systems with new technologies.

For example, in 2016 Premier Mushrooms in Colusa, California identified energy costs as a key restraint on further expansion. They invested several hundred thousand dollars in new systems to accurately regulate temperature, RH and CO_2. Room insulation was upgraded, more efficient lighting was installed and strip curtains and other related improvements were added to reduce energy use.

Premier mushrooms also changed the cooling for the growing rooms from an air-cooled system to centrifugal chiller. Centrifugal chillers are highly efficient, typically producing a cooling effect 2 to 3 times greater than the energy input[70]. This alone allowed the farm size to increase by 33% without increasing energy costs[71].

Considerations for grow room cooling equipment include:

- Flooded type evaporators have the chilled water in tubes which run through a jacket containing the refrigerant, and are highly energy efficient
- Centrifugal chillers are often most efficient when running at approximately 80% of full load; they are frequently inefficient when running at <50% loads
- Using multiple chillers allows units to be turned on or off, so all are running efficiently at close to capacity
- Increasing the chilled water supply setpoint to match cooling requirements can reduce power consumption by 1.5 to 2% per degree
- Chiller condensers and evaporators require periodic maintenance to remove accumulated scale; annual "rodding" will ensure heat transfers efficiently between the shell and tube

Cookout

Cooking out crops *in situ* at the end of their productive life is the most effective method to sanitise the rooms and prevent spread of disease. Cooking out with the compost still inside the room prevents spread of diseases such as dry bubble and cobweb to new crops within the facility. While cookout uses large amounts of energy, it ensures that subsequent crops 'start clean', which is a key fundamental in holistic farm hygiene, disease prevention and biosecurity (W. Gill, pers. com.).

[70] https://electrical-engineering-portal.com/energy-efficiency-centrifugal-water-chillers

[71] https://www.farm2ranch.com/articles/news/615/mushroom-farm-reaps-benefits-energy-efficiency/

There is limited data on heat tolerance of different mushroom diseases. Most data has been determined by lab-based trials, with a report by Overstijns[72] the key reference in this area.

This work did not, however, include green mould, which is far more heat tolerant than other pathogens. Rinker and Alm[73] found that *Trichoderma* could survive 74°C for 29 hours but was destroyed by 68°C for 42 hours. However, it has been shown that different species and strains of *Trichoderma* vary widely in their tolerance to heat, with some reliably killed by 9 hours at 60°C while others survived 36 hours at this temperature[74].

Table 19. Thermal death points of some common pests and diseases of mushrooms. From Overstijns (1998)

Pest / pathogen	Kill time (hours)		
	50°C	55°C	60°C
Most flies		5	
Nematodes		5	
Mites		5	
Cecids	1		
Trichoderma			20?
Cobweb	4		2
Dry bubble		4	2
Wet bubble	4		2
Bacterial blotch	0.17		

A wide range of time + temperature combinations for cookout are recommended in the literature. For example, Pyck and Grogan[75] recommend raising the compost to a minimum of 65–70°C for 8 hours, Beyer[76] suggests 66°C for 12 hours while Curtis[77] proposes up to 24 hours at 70°C.

If floors do not reach high enough temperatures to kill all pathogens, they can be cleaned and disinfected once the room is emptied. Trays can be treated with propiconazole (Safetray®) fungicide as extra insurance they are sanitised. However, if disease is severe, then the entire room may need to be steamed a second time after emptying. This second treatment can vary from 65°C for 2- 8 hours[75] to 24 hours at 66°C[76] or even 6-12 hours at 75°C[77] if timber trays are present.

All of these treatments are far more severe than the combinations known to kill pathogens, as shown in Table 19. This is due to the large thermal load in the rooms themselves. This is particularly an issue on older farms, where heat loss through ageing door seals, walls and exclusion mechanics allow steam to escape, thereby necessitating longer treatment times. However, no matter how rapidly the air temperature is raised, it still takes about 14 hours for the substrate to reach 60°C[78], while timber trays can take five to six times longer to heat than the substrate they contain[76]. Moreover, some farms have adopted heavy, deep dug peat instead of blonde peat, which also takes longer to achieve thermal kill (W. Gill pers. com.). Unfortunately, a number of researchers have

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[72] Overstijns A. 1998. The conventional phase II in trays or shelves. Mush. J. 584:15-21.

[73] Rinker DL, Alm G. 2000. Management of green mould disease in Canada. Mush. Sci. 15:617-623.

[74] Morris E, Harrington O, Doyle ORE. 2000. Green mould disease – The study of survival and dispersal characteristics of the weed mould Trichoderma in the Irish mushroom industry. Sci. Cult. Edible Fungi. 15:645-651.

[75] Pyck N, Grogan H. 2015. Fungal diseases of mushrooms and their control. MushTV Factsheet 04/15. www.mushtv.eu

[76] Beyer DM. 2018. Best practices for mushroom post-crop sanitation: steam-off/post-crop pasteurisation

[77] Curtis J. 2008. 2008-2009 mushroom production guide. Ministry of Ag. And Lands, Brit. Columbia.

[78] Gill, W. 2018. Putting the heat on the cookout. Aust. Mush. J. Spring 2018: 39-43.

concluded that sanitisers and fungicides alone cannot control mushroom diseases in compost, so cook-out remains an important disease control practice[79].

Conversations with growers indicate that practices used on farms vary widely. While some farms do not cook-out at all, others steam rooms for 12 hours or more.

When deciding on the time: temperature combination to use, growers must assume a worst-case scenario, as they are often unsure of what diseases may be present. However, new molecular techniques allow much faster and easier detections of pathogens.

Optimising the cook-out process, so that sufficient heat is applied to kill the pests present, could potentially provide significant energy savings. However, this requires much more information about the heat tolerance of different pathogens than is currently available.

Cook-out energy requirements can also be reduced by more efficient growing systems. Some newer mushroom farms use metal shelf systems with moving belts to grow mushrooms. These allow spent compost to be removed directly from each growing room. If compost can be removed without diseases spreading to other parts of the facility, cook-out can be conducted after the room has been emptied. This substantially reduces the amount of heating required.

Even if the compost is treated *in situ*, metal shelves heat much faster than wooden trays. Wooden trays are particularly difficult to sanitise, as pathogens can harbour deep within the timber. Changing from wooden to metal systems will therefore significantly reduced the cook-out time needed to ensure proper sanitation.

Figure 45. Galvanised belt and shelf systems allow more efficient cook-out than older tray systems

In summary, the energy used for cookout may be minimised by:

- Ensuring all doors, vents and wall joints are well sealed and insulated
- Understanding what diseases and pathogens are present; times and temperatures required to control green mould are far greater than those needed to manage diseases, which in turn are higher than those needed to control invertebrate pests
- Using a higher temperature with shorter duration where appropriate
- Changing from wooden to metal shelving

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[79] Baars J, Rutjens J. 2016. Finding a suitable biocide for use in the mushroom industry. Sci. Cult. Edible Fungi. 114-117.

- Installing a belt system to remove compost directly from the room before cookout
- Combining cookout with cleaning and disinfection of floors, walls etc.
- Not allowing pathogen levels to build up, thereby necessitating double cookouts

Whole farm facilities

Systems such as **Profarm** (Denso Corporation, Japan) use large numbers of sensors installed across compost, power systems, atmosphere, ventilation systems, irrigation etc. to provide real-time tracking of growing conditions. This data is analysed by the cloud-based software system, correlating environmental changes with yield and quality data. Tracking inputs potentially allows the user to find efficiencies in energy and water use as well as optimising production.

Cooling tower fans, condensers, water pumps, and air and water distribution systems can all be analysed to identify potential energy efficiencies. About half the cooling load in inefficient buildings can come from solar radiation and poor lighting choices[80]. Mushroom farms have the advantage of lacking windows, and many farms have already installed energy efficient LED systems, but may be able to improve efficiency in other ways:

- Adding extra insulation to the roof
- Ensuring concrete floors are well insulated and sealed against moisture
- Checking there are no leaks that allow water to enter internal panelling; if insulation is wet it will be ineffective
- Light coloured roof coating to reflect solar radiation
- Spraying wastewater on the roof to provide evaporative cooling
- Maximising structural overhangs (eaves) on north facing walls
- Planting trees around the building to provide shade and evapotranspiration

Cooling

Many farms already use vacuum cooling systems to reduce the temperature of harvested mushrooms. While the capital costs of vacuum coolers are high, they are far more energy efficient than either forced air or room cooling systems. This is because nearly 100% of the energy used directly cools the product, rather than cooling air, cold room panels, fans, pumps, packaging etc. as occurs with forced air or room cooling. Vacuum coolers operate most efficiently when fully loaded; the same amount of energy is needed to cool a half load as a full one[81].

[80] http://energy-models.com/hvac-centrifugal-chillers

[81] Thompson J. 2001. Energy conservation in cold storage and cooling operations. Perishables Handling Quarterly Issue 105. UC Davis.

12.2 Energy generation on-farm

Financial benefits of energy generation

Generation of power on-farm can not only reduce reliance on external energy sources, but also generate independent revenue for the business.

The Large-scale Renewable Energy Target (LRET) creates incentives for energy producers such as those on farms through the creation and sale of large-scale generation certificates (LGCs). Electricity retailers are required to produce a percentage of power from renewable sources. This target has been increasing annually, and in 2020 was set at 19.31%. Retailers meet their LRET requirement by surrendering approximately 33.7 million LGCs annually. If they fail to do so they are required to pay a non-tax deductible shortfall charge, so are strongly incentivised to achieve this.

Accredited power stations (total capacity >100kW, as measured at the meter) using a renewable energy source – such as wind, solar, agricultural waste, wood waste etc. –generate 1 LGC for every 1MWh electricity produced. The LGCs are created on a monthly or annual basis based on the total amount of electricity produced, whether this energy is exported to the grid or used on-site.

The producer is then able to sell their LGCs to coal-fired power retailers for them to meet their compliance obligations. They can also sell LGCs to companies that want to offset their carbon footprint.

As renewable power generation has increased, the spot price of LGCs has declined, falling from $71.90 in October 2018 to $39 in February 2019. According to the Australian Clean Energy Regulator in 2019, prices for 2020 are forecast to be approximately $23.60. Despite this fall, LGCs provide an ongoing revenue stream for the operator in addition to savings in energy costs. Moreover, it seems likely that the LRET will increase considerably in the future, as Australia attempts to meet emission reduction targets.

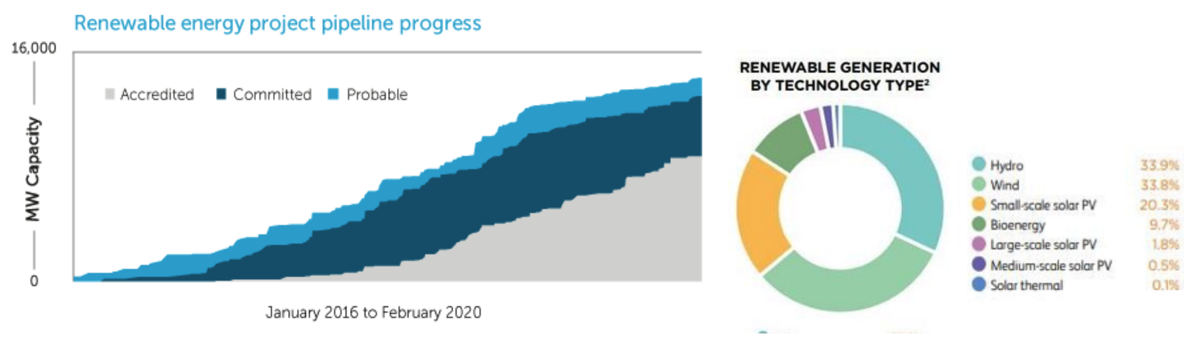

Figure 46. Progress towards the renewable energy target (cleanenergyregulator.gov.au) and renewable energy by source (Clean Energy Report 2018)

Small scale generation systems (rated to 100kW, up to 250MWh annually) cannot produce LGCs but are entitled to small-scale technology certificates (STCs). These can be sold to recoup part of the cost of purchasing and installing the system. Small generation systems could include, for example, an 80kW solar pump system on a farm which is not connected to the grid.

Solar power generation

The large roof area of mushroom farms makes them a clear candidate for solar PV energy. The costs of solar energy are falling while at the same time the efficiency of energy production has increased. Moreover, the panels shade the roof, reducing radiant heat load on the building.

AHR studied the feasibility of on-farm solar, as well as wind and gas generation, in a project for the vegetable industry[82] ***click here for the report and factsheets***. The primary indicator of viability was whether electricity can be consumed during sunlight hours, for which typical mushroom farming is well suited. The study showed that solar PV can be viable at a 10% Internal Rate of Return (IRR) with a 5 – 7 year payback period if **electricity costs are currently more than 12 – 15 c/kWh**, and **solar costs are rapidly falling** – both in generation and storage technology.

One of the drawbacks of solar energy has been the lack of storage facility ie batteries. However, these too are becoming more price competitive. For example, the Tesla Powerpack system can provide up to 2.5MW power. This can be used to shift demand, reducing reliance on high priced energy, alleviate peaks in system load and provide emergency backup in the event of a power cut.

Solar systems have already been installed, or are planned to be installed, by a number of mushroom farms, both in Australia and overseas. For example:

> **Costa Mushrooms in South Australia** is planning to invest in a large solar PV installation to help alleviate energy costs and ensure a consistent supply of electricity, which is a significant concern after inventory losses due to power outages in the area[83].
>
> **SJW Mushrooms in Qld** has installed a 60kW solar PV system to control energy costs and ensure electricity supply to the farm, especially the climate control systems[84].
>
> **Margins Mushrooms on the NSW Central Coast** invested in a major solar PV system in 2016 and this meets about 85% of their daytime energy needs, rarely feeding into the grid.
>
> **Malboro Mushrooms in Pennsylvania, US** installed a massive 1.13MW (5000 panels) solar system to offset their energy use at cost of $US5M. They reduced their electricity bill from $25,000 per month to $5,000 per month.

Concentrated solar power

Concentrated solar power (CSP), also known as concentrating solar power, concentrated solar thermal) systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight onto a receiver. Electricity is generated when the concentrated light is converted to heat (solar thermal energy), which drives a heat engine (usually a steam turbine) connected to an electrical power generator or powers a thermochemical reaction[85]. Commercial providers can supply these systems as an alternative to solar PV.

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[82] Rogers, G. 2014. On farm power generation options for Australian vegetable growers (VG13051) Hort Innovation final report

[83] https://www.solarquotes.com.au/blog/costa-mushrooms-solar-power-mb0057/

[84] https://www.sunshinecoastdaily.com.au/news/solar-power-mushrooms/2157219/

[85] Wikipedia https://en.wikipedia.org/wiki/Concentrated_solar_power

Biogas

Biogas is produced by the anaerobic digestion of organic matter. It is typically 50-70% methane and 25-45% CO_2 with other gases in small volumes. The biogas can be used directly onsite to produce heat or converted into electricity.

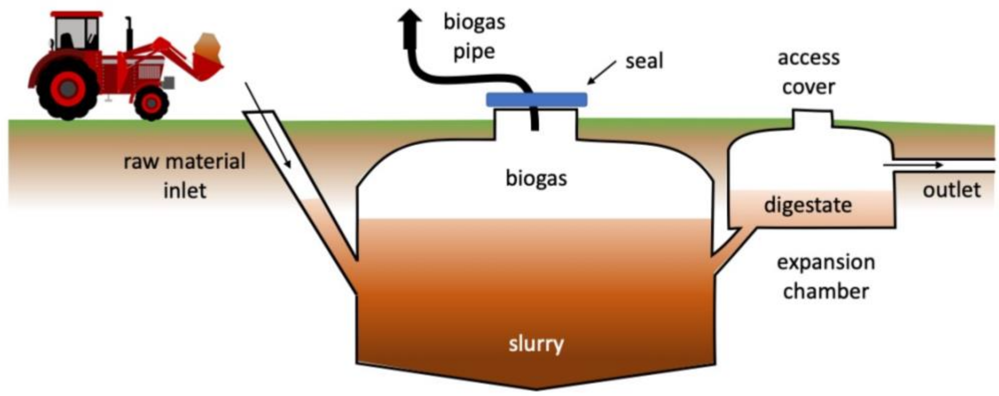

Figure 47. Biogas plant.

Alternatively, the biogas can be refined into biomethane. If hydrogen can be added, then CO_2 within the mixture can also be converted to biomethane, nearly doubling the amount of gas produced. Biomethane has the same properties as natural gas. Compressed natural gas can readily be used to power vehicles. For example, Waitrose in the UK has introduced a fleet of 50 compressed biomethane-fuelled trucks, reducing their CO_2 emissions by approx. 90%[86]. Biomethane is also being used to fuel buses in Nottingham and British Post Office long haul trucks[87].

Figure 48. Waitrose truck powered by biomethane. Photo by Scania Waitrose.

Biogas has the advantage over solar energy in that it can be readily stored for later use and can be used to heat, power vehicles or create electricity. Anaerobic digestion also produces nutrient rich digestate. The anaerobic digestion process has been shown to achieve a one-log reduction in human pathogens within 2.5 days at 35°C, and less than one day at 53°C. Both plant pathogens and weed

[86] https://resource.co/article/waitrose-run-hgv-fleet-biomethane

[87] Morton C. 2019. Decarbonising transport: the biomethane solution. https://advancedfleetmanagementconsulting.com/eng/2019/11/03/decarbonising-transport-the-biomethane-solution/

seeds are also destroyed during the digestion process[88]. As a result, the digestate can safely be used as a fertiliser[89], especially if it is dried and pelletised.

There are already an estimated 132,000 small, medium and large digesters around the world. However, there is huge capacity to expand this technology; it is estimated that only 2% of organic wastes (e.g. food wastes, sewage, manure) that could be used to generate biogas are currently used for this purpose. According to the World Biogas Association, this technology could cut global emissions by up to 4billion tonnes of CO_2 equivalent annually, reducing global emissions by up to 12% by 2030[90].

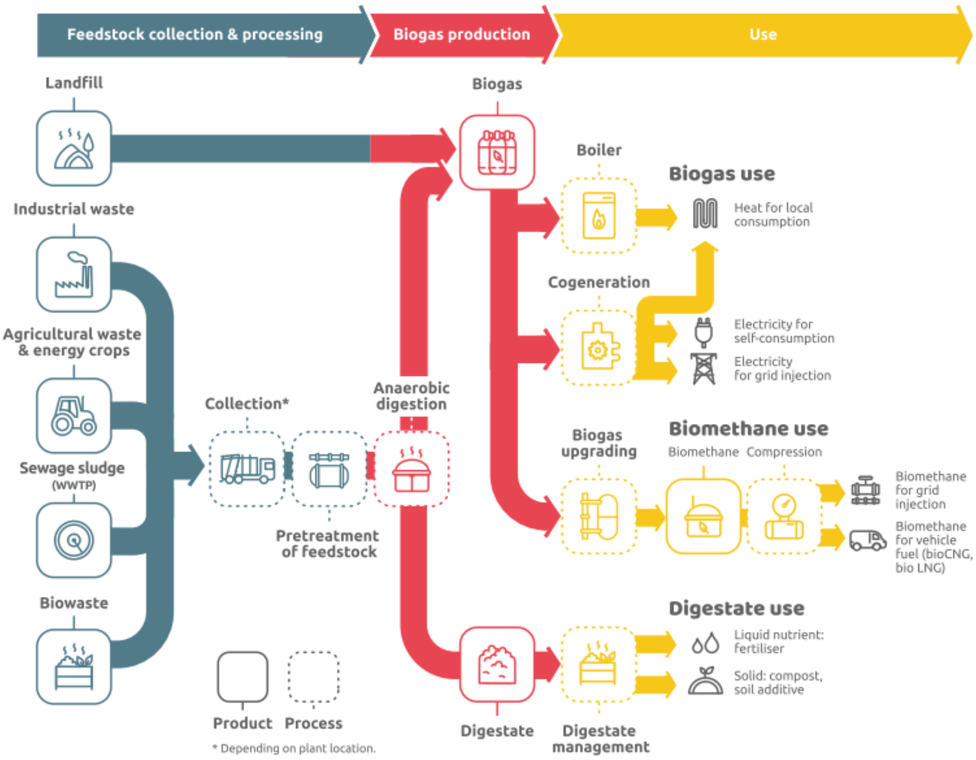

Figure 49. Biogas production. From Carlu et al, 2019.

In 2014 the feasibility of biogas was explored by Hort Innovation with the Australian vegetable industry[91]. The team determined that there were four key factors determining the feasibility of biogas:

1. The suitability of spent mushroom compost and mushroom waste as a substrate for biogas
2. The quantity of spent mushroom compost and mushroom waste available each day
3. The cost of electricity
4. Capital investment required and the payback period

At that time it was considered a farm would need to produce at least 25t of biogas-suitable waste per day. Consistency of materials was one of the key factors limiting adoption by the vegetable industry, but this would be much less of an issue for mushroom farms.

[88] Al Seadi T, Lukehurst C. 2012. Quality management of digestate from biogas plants used as fertiliser. Report by IEA Bioenergy.
[89] Carlu E, Truong T, Kundevski M. 2019. Biogas opportunities for Australia. ENEA Consulting.
[90] Anon. 2020. Putting biogas at the heart of the economy. Energy World, February 2020. p22-24.
[91] Borland, A. (2014) Biogas generation feasibility study. Hort Innovation project report VG13049.

In 2017, there were 242 biogas plants in the country, half of which were landfills collecting landfill gas. The Australian Renewable Energy Agency[92] (ARENA) commissioned an extensive review of biogas opportunities for Australia, and this review can be downloaded here [93].

There has been considerable work on generating biogas from mushroom farm wastes, particularly trimmed stalks and spent mushroom compost (SMC). The process may be even more attractive as biogas digestors produce CO_2, which can be required in mushroom growing rooms to control pinning.

A recent review of biogas production notes that fungi are effective at breaking down lignocelluloses in different types of organic wastes. This make the waste products (eg wood, compost etc) more easily processed for biogas production by removing the need for pre-treatment with physical or chemical processes[97]. They suggest that waste products from mushroom production are therefore very suitable for biogas production.

However, according to Feng et al[94], the production of methane from SMC used to grow *Agaricus bisporus* is generally lower than other substrates. A mixture of SMC and casing material produced only 67 L methane/kg solids. This compares to 155 L methane/kg sewage sludge and 531 L methane/kg food waste[95]. Unfortunately, it is not clear from this work whether the casing layer was removed before digestion; it seems likely that peat is not very suitable for biogas production due to its low nutrient content. For biogas production from SMC to be efficient, it seems likely that it needs to be separated from the casing layer before processing.

The "SmartMushroom" project currently underway in Europe aims to recycle separated SMC into both biogas and a pelletised organic fertiliser. In Europe, 3.65MTonnes of SMC are produced annually. The Netherlands has a number of large mushroom farms, however SMC cannot be disposed of within the Netherlands. The material therefore needs to be transported to Germany for disposal at significant cost.

According to Dr Thomas Helle, MD of Novis GmbH in Tübingen, Germany, mushroom compost is difficult to ferment, being low in nutrients and high in insoluble fibre. However, addition of certain fungal additives and enzymes can increase biogas production by 200-300%[96]. Increasing the temperature also helps to reduce salt content in the digestate produced.

The SMC is partially digested using a two-stage anaerobic process. Biogas produced can be used to generate electricity, as well as fuel a dryer to remove moisture from digestate and remaining SMC. The dried material can then be pelletised (along with additional nutrients if required), forming a readily transportable organic fertiliser.

A pilot plant is currently being built in La Rioja, Spain's largest mushroom growing area. If this is successful, further plants are planned in six European countries.

[92] ARENA https://arena.gov.au

[93] Biogas opportunities for Australia (March 2019) https://arena.gov.au/assets/2019/06/biogas-opportunities-for-australia.pdf accessed 14/2/2020

[94] Feng X, Castillo, M del P, Schnürer, A. 2013. Fungal pre-treatment of straw for enhanced biogas yield (Malmo)

[95] Qiao W et al. 2011. Evaluation of biogas production from different biomass wastes with/without hydrothermal pretreatment. Renewable Energy. 36:3313-3318.

[96] https://biooekonomie.de/en/interview/biogas-mushrooms

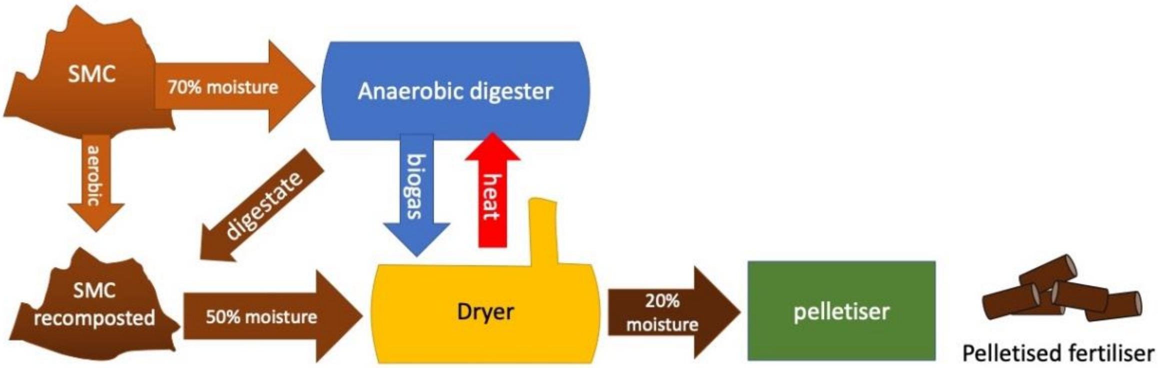

Figure 50. The SmartMushroom process. Derived from www.smartmushroom.eu

The digestate has other uses apart from fertiliser. There is some interest in testing this material as a partial replacement for peat, although salt content may prove limiting. The digestate also contains readily extractable fibres. German researchers[96] are developing natural fibre-boards based on combining these fibres with bio-based resins. The boards have properties that may make them superior to wood-based boards, and are readily composted at the end of their life cycle.

Even without these processes, biogas offers an opportunity for sustainable use of resources[97]. With 350,000 tonnes of spent mushroom compost SMS produced each year in Australia it should be considered as a promising alternative for clean energy production as mono- or co-substrate in anaerobic digestion.

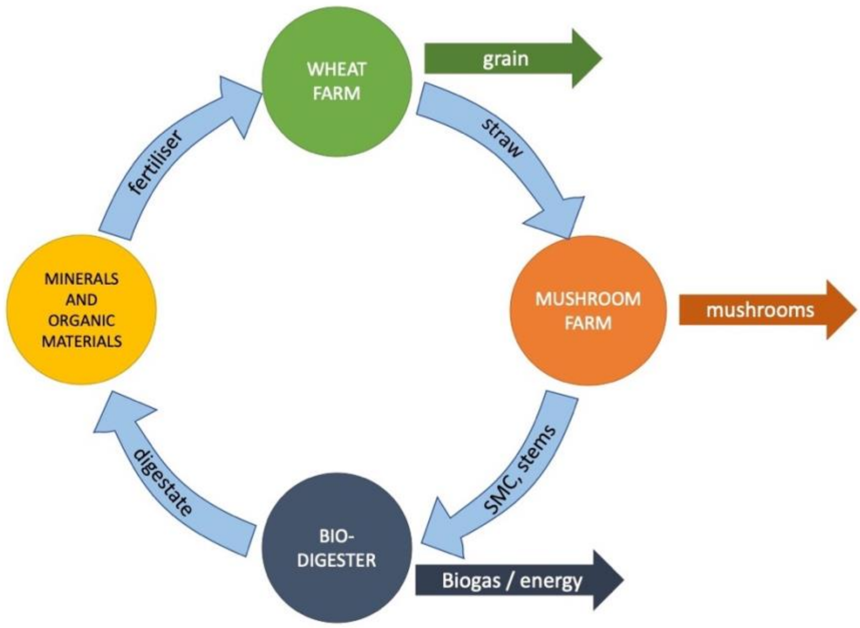

Figure 51. The "virtuous circle": sustainable production of biogas from mushroom wastes. From Perez-Chavez et al. 2019.

[97] Perez-Chavez AM, Mayer L, Alberton E. 2019. Mushroom cultivation and biogas production: A sustainable reuse of organic resources. Energy for Sustainable Dev. 50:50-60.

There are a number of companies offering biogas systems in Australia - including:

- Bioenergy Australia. https://www.bioenergyaustralia.org.au
- Utilitas https://utilitas.com.au/
- Biogass Renewables Pty Ltd. http://www.biogass.com.au/
- Hitachi Zosen INOVA http://www.hz-inova.com/cms/en/home/
- ReNu Energy. https://renuenergy.com.au/

Companies who install biogas systems can test SMCs for their suitability for this process. They are also able to advise on the payback period for what would be a significant capital investment. Costs may further be offset by sales of credits to the LRET scheme or funding through the Australian Renewable Energy Agency (ARENA).

For example, in 2014 Utilitas conducted a study on biogas production from vegetable wastes. At that time, electricity could be produced by biogas for about $80 - $160/MWh, including a payback period for capital investment of 5 years. As electricity returned to the grid earns a maximum of $110/MWh, biogas is only economically viable if the energy produced is used on-site. However, this is unlikely to be an issue for mushroom farms given the large energy costs inherent in production.

Bio-hydrogen

Researchers in Taiwan[98] have developed a process to convert SMC to hydrogen gas. Hydrogen is considered to be a potential alternative to fossil fuels; it can be produced from biological processes, and produces water on combustion. The process is complex, involving grinding of the substrate, reaction with sulfuric acid, then combining with sewage sludge and heating to 37°C at pH 7 to produce hydrogen, along with other compounds.

While this is an interesting development, it is likely to be expensive to implement on farm. However, it may be noted that hydrogen can be used to improve the efficiency of biogas production.

Biomass combustion

The simplest way to produce energy on-farm is through combustion of SMC. It is estimated that each kg of mushrooms requires production of 3-5kg compost. At least 70,000 tonnes of mushrooms are produced annually, suggesting that 350,000 tonnes is available for energy production.

A study by Finney et al[99] examined using raw SMC (including the casing material) and pelletised coal tailings (mining waste) to generate energy. Three different methods were tested:

1. ***Fluidised bed combustion*** (fuel is placed on a bed of heated sand with jets of oxygen blown through it, promoting rapid high temperature oxidation of low grade, unprocessed materials)
2. **Packed bed** for combustion and gasification (solid fuels are burned (oxidised) on a grate with air supplied from below, reaching very high temperatures eg >1,000°C)
3. ***Pyrolysis*** (materials heated to extreme high temperature in the absence of oxygen, producing energy as well as biochar)

The fluidised bed had greater energy efficiency than the packed bed. However, both methods were self-sustaining and produced useful amounts of heat and, therefore, power. The process was

[98] Li Y-C et al. 2011. Hydrogen production from mushroom farm waste with a two-step acid hydrolysis process. Int. J. Hydrogen Energy. 36:14245-14251.

[99] Finney KN, Ryu C, Sharifi VN, Swithenbank J. 2009. The reuse of spent mushroom compost and coal tailings for energy recovery: Comparison of thermal treatment technologies. Bioresource Tech. 100:310:315.

improved if the SMC was pelletised and combined with the coal tailing pellets, as pellets burn more efficiently. While pyroliysis produced reasonable volumes of biochar as well as liquid and gaseous fuels, the authors considered that yields were not high enough to justify investment in this technology.

It should be noted that this study used compost that was only approximately 15% moisture; it is unclear whether the SMC and casing was actively or passively dried. If the materials need to be dried then this would clearly affect the end yield of energy. However, once started, the process could presumably sustain itself.

It may also be possible to combust other sources of biomass. For example, **Premier Mushrooms, California, US** generates one third of its power through three biomass powered generator systems. The BioMax 100 system runs on walnut shells and had produced more than 1.5million kilowatt-hours less than a year after installation.

13 Climate adaptation – Alternative inputs

13.1 Carbon sources for compost

Availability and cost of straw is a key issue facing compost producers. Substantial research has examined substitutes for wheat straw, using alternative materials that are locally abundant. Examples include rice straw in Asia[100], sugar cane waste in Africa[101] and maize in the USA[102].

The feasibility of alternative carbon sources for Australian mushroom production were recently reviewed in a Hort Innovation project *Summary of potential alternative carbon sources and feasibility of carbon alternatives* [103]. From an initial list of twenty-four potential carbon sources identified, only four had appropriate physico-chemical properties, were reliably available and were potentially economically viable in terms of cost. The researchers consider that all four of these options are likely to continue to be available with the predicted climate change. These were:

1. Waste paper
2. Forestry waste
3. Corn stover
4. Sugar bagasse

The inclusion of waste paper within compost is limited to around 20% due to its physical properties. Forestry residuals such as bark and wood chips have better structure, but are extremely carbon rich and would need appropriate pre-treatment before composting. While both corn stover and sugar bagasse are relatively easy substitutes for wheat straw in composting, transport distances create a challenge, especially for southern producers.

The authors also considered green waste, as this material is readily available and likely to increase. However, variability in composition was considered a major hurdle; during summer green waste is likely to contain large amounts of nitrogen-rich grass clippings and prunings, whereas in autumn, dry leaves make up a larger proportion. Re-adjusting every batch so as to produce consistent material is a barrier to use. There is also concern over levels of contaminants in this material, especially if it includes kerbside collections.

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[100] Song T-t et al. 2014. Comparison of microbial communities and histological changes in Phase I rice straw based *Agaricus bisporus* compost prepared using two composting methods. Sci. Hortic. 174:96-104.

[101] Jesus JPF et al. 2013. Yield of different white button strains in sugar cane by-product based composts. African J. Ag. Res. 8:824-831.

[102] Pecchia JA, Beyer DM, Xiao L. 2016. The use of corn stover to replace straw in compost formulations for the production of *Agaricus bisporus*. The Spawn Run Sept. 2016:9-11.

[103] Wilkinson K, Jasonsmith JF, Drake J. 2019. Summary of potential alternative carbon sources and feasibility of carbon alternatives. Hort Innovation Final Report MU17007, Appendix 1.

13.2 Replacing peat

While alternative casing materials have been widely researched since the 1980s, South Africa has long been a leader in this field. African mushroom producers were unable to use locally available peat due to its high clay content, and it is now protected from exploitation in any case. Purchasing peat from Europe was initially impossible and later prohibitively expensive. As a result, South African company Mabu Casing has developed a casing material based on sugarcane bagasse that has been processed to make paper. The process is clearly confidential, but the results appear to be commercially viable.

Spent mushroom compost

The casing material that has received most attention is spent mushroom compost (SMC). This is an attractive option as it can reduce both the cost of casing and issues with disposal of spent compost. Numerous research papers detail methods for using SMC alone, or in combination with other materials (including peat), as casing. The main drawbacks of SMC are its variable composition, relatively poor water holding capacity and high salinity[104,105]. Despite this, new techniques to leach salts and improve water holding capacity could improve the viability of this material in the future.

Recycling casing

It may also be possible to partially re-cycle casing soil. Researchers in the Netherlands[106] have developed a method to separate casing from the underlying compost. The researchers propose that, to ensure good separation, mycelium should be allowed to thoroughly colonise the underlying compost under high CO_2 (1%), before the casing is added. At the end of the cropping cycle the casing is removed, ground, steam sterilised and then inoculated with bacteria. It is recommended to add up to 30% of the recycled material to fresh peat.

This system is now commercially available and sold as the “Mush Comb Separator”. The separator works with the emptying conveyor and winch in shelf rooms. The separator is placed against the shelving, with the emptying winch on the other side. Casing is unloaded onto a separate conveyor and taken off to the side[107]. The process does not limit the speed of unloading for the room; it can operate at 17m/minute, which is faster than most emptying systems usually run.

Separating wet peat from the underlying compost also facilitates use of the SMC for power generation on farm, either through direct incineration or biogas production.

[104] Riahi H, Zamani H. 2008. Use of spent mushroom compost and composted azolla as an alternative for casing soil. Proc. ISMS. 17:333-339.

[105] Barry J et al. 2008. Partial substitution of peat with spent mushroom substrate in peat-based casing blends. Proc. ISMS 17:288-309.

[106] Oei P, Albert G. 2012. Recycling casing soil. Proc ISMS 18:757-765.

[107] www.mushcomb.com

Figure 52. The Mush Comb unit (a) is used to separate the casing from compost during room unloading. The separator is used with a multi-arm emptying machine (b) as the crop is removed after final harvest (c). Conveyors take compost into the waiting trailer, while casing is diverted to a container at one side (d). The separated casing soil (e) and compost can then be recycled or used for other purposes. Photos by Mush Comb (www.mushcomb.com) and The Mushroom People (www.themushroompeople.com).

Recycled organics

Recent Australian trials conducted by AHR have focussed on using recycled organics from green waste as casing materials. The green waste is prepared from landscape wastes rather than the more variable materials collected from domestic recycling. It is thoroughly composted, ground and aged before use, Blends of up to 50% recycled organics (RO) with peat have resulted in similar yield and quality to peat alone. While these are initial trials only, the results appear promising, especially if the EC content of the recycled organics can be further reduced through leaching.

Figure 53. Mushrooms growing with (from left to right) 100% RO; 50:50 RO to peat blend; 25:75 RO to peat blend or peat only. Yield was not significantly affected by inclusion of up to 50% RO with peat in the casing.

13.3 Efficient use of water

Many compost producers and growers already recycle significant volumes of water and have adopted efficient water use practices. Recycling and use of bore water can be limited by contamination with salts and organic material. These issues may potentially be overcome with new water purification systems. For example, multinational companies such as Suez supply high capacity treatment equipment for recirculating aquaculture systems. These can remove dissolved salts, organic matter, bacteria and even viruses.

Mushrooms are usually irrigated using a sprinkler system. However, sprinklers cannot be used when mushrooms are emerging. Netafim has developed a drip irrigation system called “Mushroom Master™“. The drip system maintains uniform moisture levels through the compost and casing material, reducing the need for heavy watering between flushes. It is claimed that the system reduces total water use and energy costs by up to 20%, as well as reducing the thickness of the casing required by up to 30%. Moreover, as uniform moisture improves mushroom density, quality and storage life may be improved. The system is currently used in at least three farms internationally.

Figure 54. Netafim "Mushroom Master" irrigation system

14 Conclusions and key findings

Greenhouse gas emissions: The team reviewed three separate life cycle studies that measured greenhouse gas emissions from mushroom farms in Australia. Estimated emissions were 2.1 to 4.4 kg CO_2-e per kg mushrooms produced. Most of the emissions come from energy used for heating and cooling, from compost production, and transport of raw materials. While these results appear generally consistent, the inclusions and methodology in each study varied widely. For example, one suggested that release of gasses during composting was a key source of emissions, whereas others did not include this in their calculations. Moreover, none included CO_2 released as a result of peat extraction.

Predicted changes to the climate in each of the mushroom and compost producing regions: The predicted climate changes by 2070 were modelled for the following six regions in Australia:

- Sydney and the Hunter Valley, NSW
- Brisbane, Queensland
- Perth, Western Australia
- Mildura and Melbourne, Victoria
- Hobart, Tasmania
- Adelaide, South Australia

Potential changes in annual climate are provided for 2050 and 2070 and include maximum and minimum temperatures, rainfall, relative humidity, solar radiation and windspeed. These provide an indication of potential future climates depending on how Australia and the rest of the world respond to the challenge of reducing greenhouse emissions.

In addition, the potential climate extremes are provided for the hottest day and coldest night. These "unpack" the annual averages and provide an indication of what potential changes in extremes could occur in 30 and 50 years under the two scenarios.

Alarmingly, the average number of days above 35°C during the past 12 months (May 2019 – April 2020) for most regions in Australia were already close to, or exceeding, the long-term average number of hot days (over 35°C) expected by 2050.

Expected impact on pests and diseases: The following pest and disease-related issues are expected to increase in severity or significance with climate change:

- Dispersal of established diseases due to greater sciarid and phorid fly activity and increased populations will spread disease
- Dry conditions will facilitate air and dust-borne pathogen dispersal
- Increased incidence of mites and nematodes
- Increase in weed moulds
- Establishment of emerging diseases will increase facilitated by increased insect activity assisting spread. The greatest risk is from Trichoderma aggressivum f. aggressivum as it is adapted to bulk Phase III handling systems

15 Recommendations

This review has revealed a number of gaps in knowledge or practice which could be investigated further by the mushroom industry.

15.1 Identify and test alternative casing materials

It is very likely that peat will become less available and, therefore, more expensive as many countries attempt to reduce their carbon emissions. However, the peat used for casing is clearly an essential input to mushroom production, with no ready alternative.

Alternatives to peat as a casing material have been trialled in a number of countries. Countries which are unable to source peat locally, or which find the cost of imported peat prohibitive, have already been forced to find full or part replacements. Examples include the Mabu casing in South Africa, which is made from sugarcane waste and Malard mushrooms in Iran, which use a 50:50 blend of peat with spent mushroom compost (SMC). Preliminary trials by AHJR have identified that well composted and finely ground green waste can be mixed up to 50:50 with peat without affecting yield. In addition, new equipment is available which can separate the casing layer from compost, which would facilitate recycling of this material.

It is proposed that the industry consider investigating these, and other, potential replacements for peat. Promising alternatives include:

- Composted green waste
- Pasteurised, ground and recycled peat
- Pasteurised spent mushroom compost

One of the issues with using pasteurised products is that they lack the *Pseudomonads* and other bacteria believed to be responsible for degrading carbon volatiles produced by the *Agaricus* mycelia. Pasteurised products have therefore had limited success in stimulating formation of primordia. However, these bacteria could be inoculated into the casing material, potentially with activated charcoal – which may have a similar effect.

15.2 Optimise compost made from lower quality, shorter straw and different manure sources

In recognition of the ongoing issues with obtaining wheat straw, a recent study was conducted assessing alternative substrates for mushroom production (MU17007). The study concluded that wheat straw has unique properties for compost production which are hard to replicate. Corn waste, sugar bagasse, wood waste and paper waste were all considered, but were likely only to be suitable as partial replacements.

It is unlikely that wheat straw will become unavailable for compost production. However, as many farmers transition to minimum till, long stubble systems, its quality attributes will change. Straw may also vary with age – green straw may be less suitable for composting, whereas stockpiled straw may have reduced nutrient value.

Helping compost producers adapt to shorter materials, possibly of lower quality, is key to ensuring the productivity of this material when it reaches the farm.

Just as wheat farmers are changing their practices to adapt to climate change, so too are chicken producers. The effect of changes in diet, bedding materials and re-use of bedding on the attributes of manure is not understood. Analysing a range of different manure products would help composters optimise compost production.

Examination of the effects of changes in straw and manure quality would link with current research lead by Michael Kertesz. Dr Kertesz is currently investigating optimum nitrogen transformation in compost (MU17004) and how the microbial populations in mushroom compost can be used to change compost quality (MU17006).

Trial materials could be produced which;

- Include inoculations of beneficial microbes
- Mix in alternative carbon sources such as bagasse, cotton trash or corn stover
- Utilise wheat straw of different qualities / lengths and age

Trial crops would then be grown with these composts to examine yield and quality of the mushrooms produced.

15.3 Evaluate the use of soil moisture sensors for managing irrigation in mushroom growing

For many horticultural producers, water availability and quality is a key factor limiting the crops they can produce. As a result, irrigation is frequently precisely controlled. It is relatively common for growers to install networks of soil moisture sensors, with water application through drippers or sprinklers controlled using computerised systems.

Water for irrigation is not a limitation on mushroom farms. For this reason, irrigation is usually controlled manually, or using a semi-automated timer system. However, water may have significant effects on mushroom quality.

The effect of irrigation practices on mushroom yield and quality will be examined in project MU19005 *New innovations to improve mushroom whiteness and shelf life*. This will identify optimum moisture content of compost and casing for mushroom production.

However, only by monitoring moisture content through the layers of casing and compost can irrigation be accurately controlled. Many different types of soil moisture sensors exist. However, they are not generally used for mushroom production. It is proposed that, based on recommendations from MU19005, the industry investigate:

- What types of sensors are most suitable for monitoring moisture in compost and casing (eg TDR, capacitance or standing wave)
- How these sensors can be used to improve management of irrigation on mushroom farms

15.4 Develop a smart cookout approach using qPCR disease identification to determine pathogens present and determine when cookout is needed.

Pests and disease are a major threat to viability of mushroom farms. In order to control spread of disease through a facility, many businesses cookout their growing rooms at the end of cropping cycles. However, this practice also imposes a significant cost. Cookout not only uses a huge amount of energy, but also damages equipment and facilities, prematurely ageing them. Some mushroom farms don't cookout at all, while practices used by those that do vary widely between businesses. Times range from only a few hours to 24 hours.

The mushroom industry now has access to PCR tools to test for common diseases. These can rapidly and accurately identify the pathogens present in the growing environment. Using this information, a risk analysis approach could be used to decide whether a room needs to be cooked out, and if so, what time and temperature combination is required for efficacy.

However, this approach also needs accurate information on thermal death kinetics of pests. It is therefore proposed to:

- Verify the time / temperature combinations needed to kill common pests and diseases of mushrooms, with a particular focus on Trichoderma
- Ground truth use of the PCR test to examine the pests and diseases present in growing rooms pre and post-cookout
- Develop a risk analysis tool for the mushroom industry on what cookout process to use and when.

15.5 Understand cookout timing and temperatures required to control specific diseases in growing rooms.

Mushroom pests and diseases vary widely in their heat tolerance. Whereas cecid flies are killed by only one hour at 50°C, disinfection of cobweb requires four hours at 50°C. However, it is *Trichoderma* which is the most challenging to destroy. Estimates range from 9 to more than 36 hours at 60°C to control green mould, with wide variations between strains. Moreover, this research was conducted more than 20 years ago, and not in Australia – the heat tolerance of strains present in Australia is unclear.

15.6 Investigate likely changes in mushroom disease, including smoky mould

Smoky mould, caused by *Penicillium hermansii,* is a relatively new disease affecting Australian mushrooms. It has been linked to use of poor quality or dirty straw; survey participants suggested that the dust storms over the 2020 summer may have increased the presence of this pathogen on wheat straw. However, this connection is unclear, as the pathogen has so far only been isolated in conjunction with *Agaricus*.

South African researcher Lise Korsten is currently undertaking a project on the effects of climate change on mushroom diseases, including smoky mould. It would be useful for the Australian industry to link with this project, given our similarities in climates. It could also potentially survey the prevalence of this pathogen on raw materials and in mushroom grow rooms. This would help to assess whether smoky mould is likely to become a significant future pest for mushroom growers.

15.7 Investigate the technical feasibility and marketing opportunities of carbon neutral mushrooms

Perez-Chavez et al (2019) proposed the "virtuous circle" for mushrooms. In this system, waste from the mushroom farm is used to generate biogas. Power and digestate from the biogas are used to make fertiliser pellets, which is used to grow wheat, the straw from which can be composted and used to grow more mushrooms.

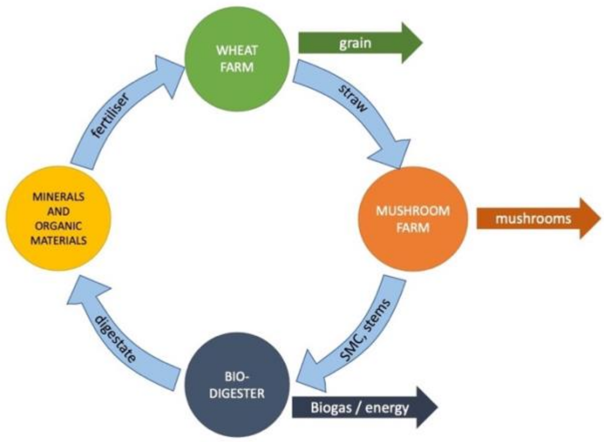

Figure 55. The virtuous circle, by Perez-Chavez et al., 2019.

The carbon footprint of different foods has become a significant issue in recent times. Meat is invariably associated with a major carbon footprint, with the result the Australian meat industry is attempting to reduce emissions. Meat and Livestock Australia (MLA) has set the target of being carbon neutral by 2030. They see this as an important issue for consumers. According to the MLA website:

"Imagine that by 2030 we saw consumers make the decision to buy red meat because they knew it was a good choice for the environment".

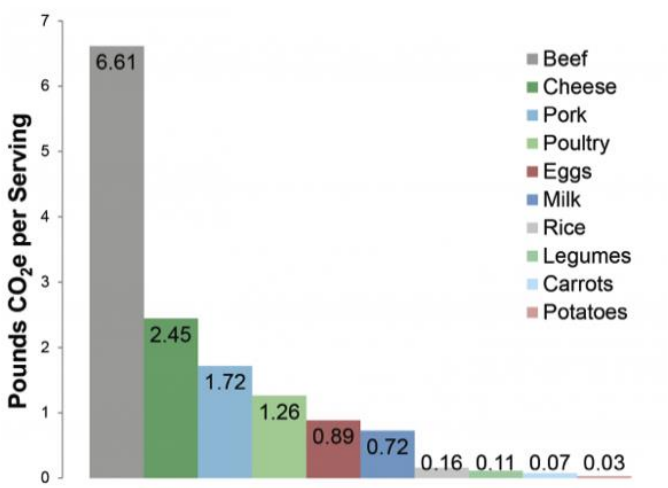

Figure 56. CO_2 equivalents per serving of different foods. From the University of Michigan, Center for Sustainable Systems

Mushrooms have an opportunity to be the first carbon neutral horticultural producer. Adoption of alternative casing materials (e.g. green waste) and/or recycling of peat, along with installation of on-farm power generation, re-cycling of waste products and high productivity under controlled conditions could all help reduce the environmental impact of mushroom production close to zero.

This could have marketing implications. Mushrooms are often considered an alternative to meat; promotion of their low environmental impact and lack of carbon footprint could provide further leverage in marketing campaigns.

The industry should investigate the opportunities to promote mushrooms as being healthy for the planet as well as for consumers.

15.8 Establish a solar buying group for mushroom producers

Based on information from the survey participants, it could be calculated that each tonne of mushrooms cost approximately $500 in electricity to produce. However, electricity costs by volume were far higher for many of the smaller farms.

The payback time for solar systems depends primarily on the price paid for electricity from the grid. While large farms may be able to negotiate favourable rates, this is more difficult for small businesses. These organisations would therefore be most likely to benefit from installation of solar systems.

The mushroom industry as a whole has strong bargaining power, even if small firms do not.

It is proposed that the industry investigate the feasibility of negotiating a group “buy-in” for solar system supply and install. This would facilitate uptake of on-farm solar generation for all industry members, and particularly for smaller businesses.

15.9 Pilot biogas energy generation on-farm

Adoption of biogas appears to be proceeding at a rapid pace in other industries. Numerous piggeries, abattoirs, waste facilities and other industries have already installed biogas plants to generate energy for use on site.

The SmartMushroom project in Europe has built a pilot plant for biogas production from SMC in Spain. Initial contact has been made with the project team, who have been open to sharing information on this innovation as it develops. It is recommended that the Australian mushroom industry link with this project in order to share in the information created. This will help determine the feasibility of this technology for Australian mushroom farms.